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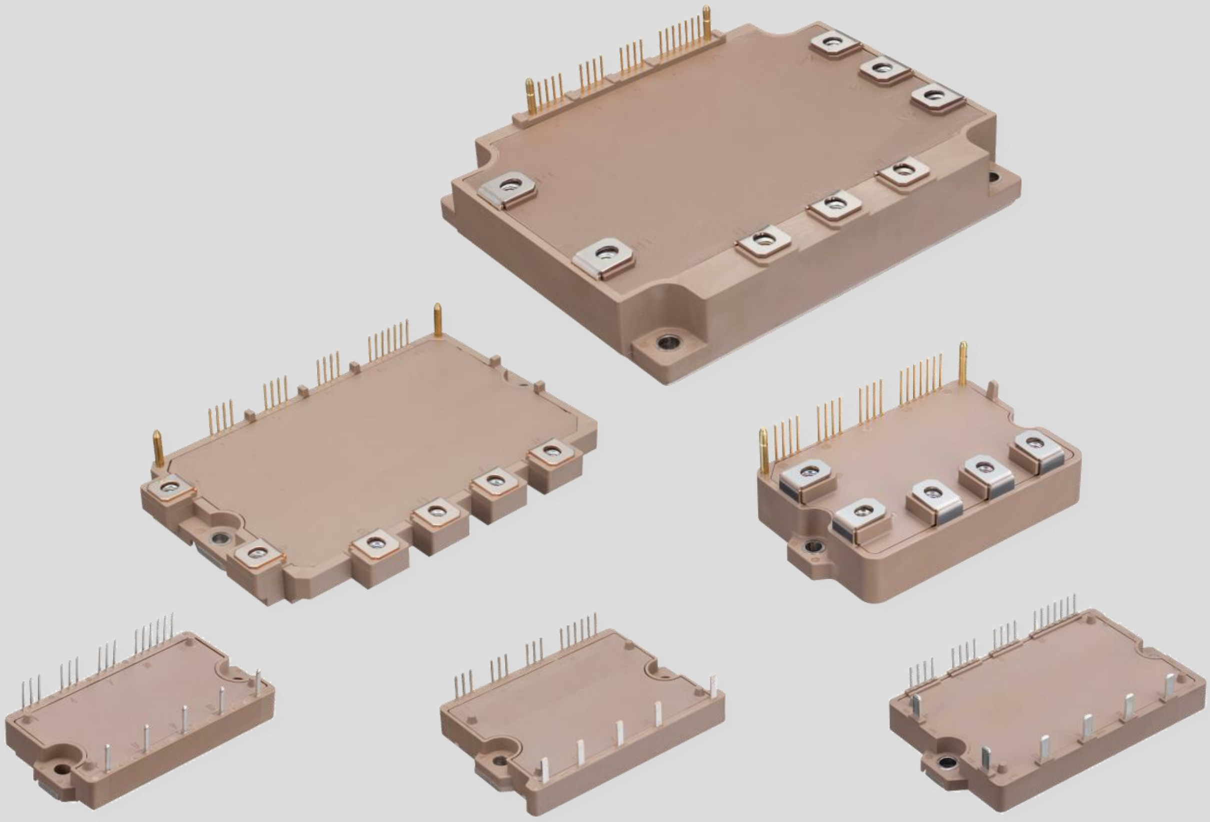

Fuji 7th Generation IGBT-IPM
X Series

X series 7G

Application Manual

Oct. 2024

Fuji Electric Co.,Ltd.

MT6M15962c

Warning:

This manual contains the product specifications, characteristics, data, materials, and structures as of October 2021.
The contents are subject to change without notice for specification changes or other reasons. When using a product listed in this manual, be sure to obtain the latest specifications.

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⚠ Cautions

(1) During transportation and storage

Keep locating the shipping carton boxes to suitable side up. Otherwise, unexpected stress might affect to the boxes. For example, bend the terminal pins, deform the inner resin case, and so on.

When you throw or drop the product, it gives the product damage.
If the product is wet with water, that it may be broken or malfunctions, please subjected to sufficient measures to rain or condensation.

Temperature and humidity of an environment during transportation are described in the specification sheet. There conditions shall be kept under the specification.

(2)Assembly environment

Since this power module device is very weak against electro static discharge, the ESD countermeasure in the assembly environment shall be suitable within the specification described in specification sheet. Especially, when the conducting pad is removed from control pins, the product is most likely to get electrical damage.

(3)Operating environment

If the product had been used in the environment with acid, organic matter, and corrosive gas (hydrogen sulfide, sulfurous acid gas), the product's performance and appearance can not be ensured easily.

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Chapter 1 Features and structure

This chapter describes the features and structure of the X series IPM.

1. Features of the IGBT-IPM

An IPM (intelligent power module) is an intelligent IGBT module combining a built-in control IC which includes a drive circuit and a protection circuit. The X-IPM (X series IPM) has the following features:

1.1 Built-in drive circuit

- Drives the IGBT under the optimized gate control conditions.
- No negative power supply is needed since it has minimum gate impedance between the drive circuit and the IGBT devices.
- Four isolated power supply units are required: one (1) on the lower arm side, three (3) on the upper arm side.

1.2 Built-in protection circuit

- Over current protection (OC), short circuit protection (SC), control power supply under voltage protection (UV), IGBT chips over heating protection (T_{jOH}) and an external alarm signal output (ALM) are integrated.
- OC and SC are functions to protect the IGBT against breakdown caused by an over current or a load short-circuit. Each IGBT has an on-chip current sensor which can detect the collector current of each IGBT. This feature can protect the IPM module against an over current and a short circuit that may occur in any IGBT.
- UV is the protective function that works against a drive power supply voltage drop. Control IC for each arm has this function.
- T_{jOH} provides a high-speed over temperature protection by using an on-chip temperature sensor.
- ALM sends an alarm signal to the outer peripheral control unit of the IPM when an OC, SC, UV and/or T_{jOH} occur. Additionally the IPM initiates a safe soft stop of the system. *1
  *1 See [Chapter 3 Description of functions] for details of protective functions of each IPM.

1.3 Built-in brake circuit (7in1 IPM)

- A brake circuit can be configured by adding an external resistor that dissipate electric power during regeneration.
- The brake circuit has a drive circuit and protection circuit, similar to the inverter unit.
- In the X series IPM, even when the inverter part of the lower arm detects an abnormality and protection is activated, the brake IGBT can operate independently. Therefore, it is possible to suppress the rise in main power supply voltage due to deceleration resulting from abnormal stop and prevent overvoltage destruction of the product.

1.4 IGBT chips temperature warning output function (specific model)

- The X series IPM has a function that notifies the IGBT chip is overheated by generating a warning signal output when the IGBT chip reaches 150°C or higher. IGBT chips over heating protection (T_{jOH}) operates by stopping the IPM and generate an alarm signal output when the IGBT chip temperature rises above 175°C. However, in the temperature warning output function, the switching operation is continued while the temperature warning signal is generated. By utilizing this function, it is possible to avoid the system from stopping by changing the operating conditions before the IPM is stopped by the over heating protection function.
  In addition, it is possible to prevent a decrease in productivity due to a sudden equipment shutdown.

1.5 RoHS regulatory compliance

• All models of the X series IPM comply with RoHS directive.

2. Part number and lot No.

Table 1-1 shows how to read the part number of the X series IPM.

Table 1-1 How to read the part number ex.) 6MBP50XBA120-50

6	MBP	50	X	B	A	120	-50
IGBT Switch number	Type of module	Current rating	IGBT Chip generation	Package	Suffix	Voltage rating	Suffix
6: without brake	MBP: Intelligent power module (IPM)	I_C x 1 (A)	X: X series (7th Gen.)	A:P629		V_{CES} x1/10 (V)	
7: with brake			XR: X series (RC-IGBT)	B:P626			
				D:P630			
				E:P631			
				F:P636			
				G:P638			
				H:P639			
				J:P644			

Table 1-2 shows how to read the lot No. of the X series IPM.

Table 1-2 How to read the lot No.

20	1	001
Production year	Production month	Serial number
19: 2019	1: January	001～999
20: 2020	2: February	
21: 2021	⋮	
	9: September	
	O: October	
	N: November	
	D: December	

Fig.1-1 shows an example of product indication for X series IPM.

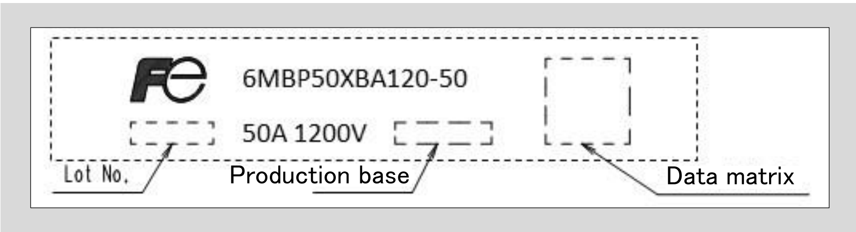


Fig.1-1 Indication   ex.)6MBP50XBA120-50

3. Line-up

Table 1-3 650V Line-up

Package	Pin type		Screw type	
	6in1	7in1	6in1	7in1
P639	6MBP20XRHA065-50			
	6MBP30XRHA065-50			
P629	6MBP50XAA065-50			
	6MBP75XAA065-50			
P626	6MBP50XBA065-50			
	6MBP75XBA065-50			
	6MBP100XBA065-50			
P644		7MBP50XJN065-50		
		7MBP75XJN065-50		
P636	6MBP100XFN065-50	7MBP100XFN065-50		
P638			6MBP100XGN065-50	
			6MBP150XGN065-50	
P630			6MBP100XDA065-50	7MBP100XDA065-50
			6MBP150XDA065-50 6MBP150XDN065-50	7MBP150XDA065-50 7MBP150XDN065-50
			6MBP200XDN065-50	7MBP200XDN065-50
			6MBP250XDN065-50	7MBP250XDN065-50
P631			6MBP200XEN065-50	7MBP200XEN065-50
			6MBP300XEN065-50	7MBP300XEN065-50
			6MBP450XEN065-50	7MBP450XEN065-50

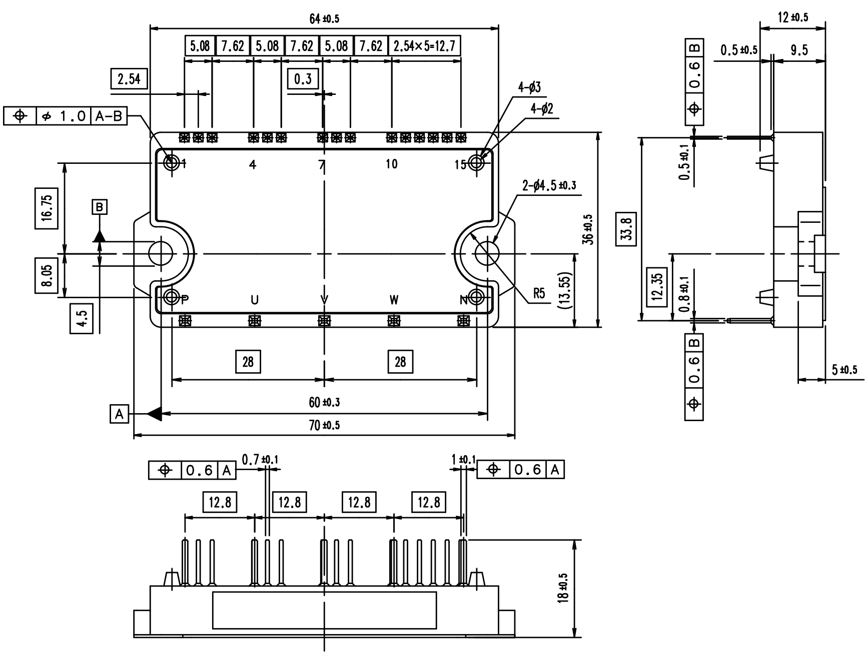
Table 1-4 1200V Line-up

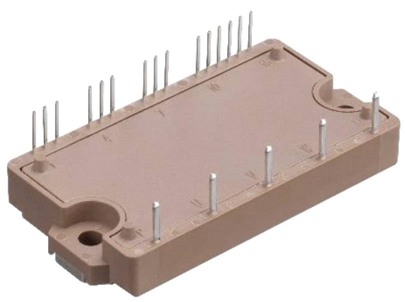
Package	Pin type 6in1	Pin type 7in1	Screw type 6in1	Screw type 7in1
P639	6MBP10XRHA120-50			
P629	6MBP25XAA120-50			
	6MBP35XAA120-50			
P626	6MBP25XBA120-50			
	6MBP35XBA120-50			
	6MBP50XBA120-50			
P644		7MBP25XJN120-50		
		7MBP35XJN120-50		
P636	6MBP50XFN120-50	7MBP50XFN120-50		
P638			6MBP50XGN120-50	
			6MBP75XGN120-50	
P630			6MBP50XDA120-50	7MBP50XDA120-50
			6MBP75XDA120-50 6MBP75XDN120-50	7MBP75XDA120-50 7MBP75XDN120-50
			6MBP100XDA120-50 6MBP100XDN120-50	7MBP100XDA120-50 7MBP100XDN120-50
			6MBP150XDN120-50	7MBP150XDN120-50
P631			6MBP100XEN120-50	7MBP100XEN120-50
			6MBP150XEN120-50	7MBP150XEN120-50
			6MBP200XEN120-50	7MBP200XEN120-50
			6MBP300XEN120-50	7MBP300XEN120-50

4. Features of each package

4.1 P639 package (6in1 with lower arm alarm signal output)

- The line-up is 20A to 30A for 650V and 10A for 1200V.
- Terminal pitch of the control terminals is standard 2.54 mm.
- Main terminals are flat type solder pin and the height is the same as the control terminals. Therefore, it is possible to solder the main terminals and control terminals to the same PCB.
- Screw size for the heat sink is M4.
- Protective function is applied to the upper arm side, but no alarm signal output function is available.
- The package outline drawing is shown in Figure 1-2.





Note:

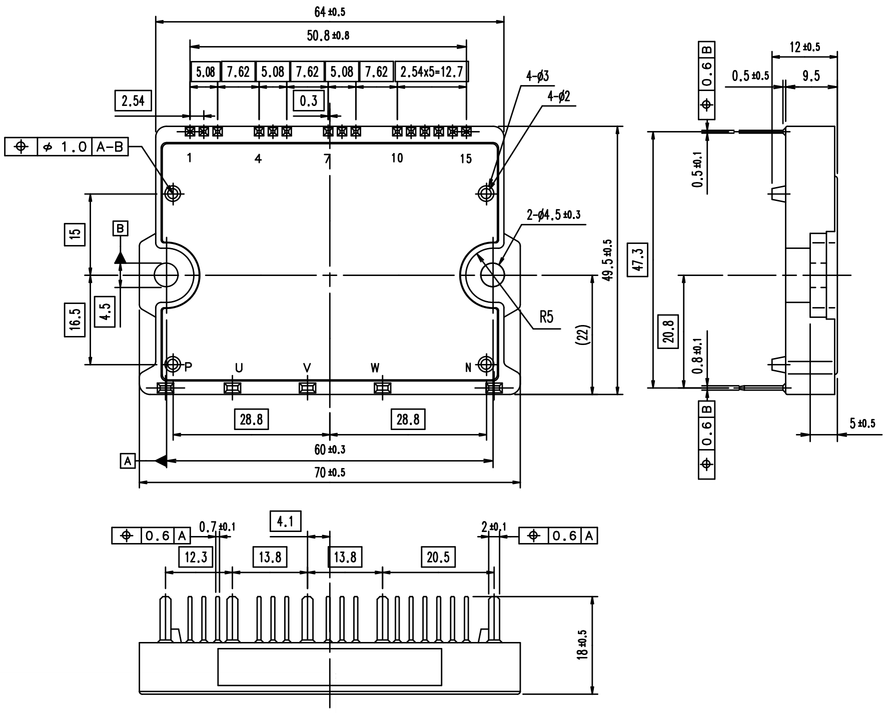
1. The dimensions shown in ☐ represent the theoretical dimension.
2. The terminal pitch is the value at the root of the terminal.
3. Dimensions in ( ) are given only for reference.
4. Terminal plating: Sn (for soldering)

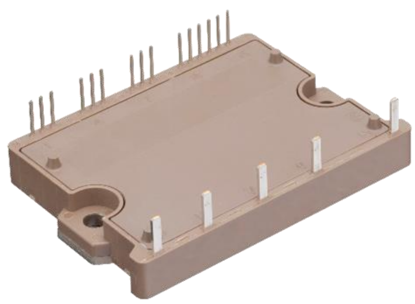
[Unit of dimensions : mm]

Fig.1-2 Package outline drawing (P639)

4.2 P629 package (6in1 with lower arm alarm signal output)

- The line-up is 50A to 75A for 650V and 25A to 35A for 1200V.
- Terminal pitch of the control terminals is standard 2.54 mm.
- Main terminals are flat type solder pin and the height is the same as the control terminals. Therefore, it is possible to solder the main terminals and control terminals to the same PCB.
- Screw size for the heat sink is M4.
- Compatible mounting dimensions with the R-IPM series P619 package.
- Protective function is applied to the upper arm side, but no alarm signal output function is available.
- The package outline drawing is shown in Figure 1-3.





Note:

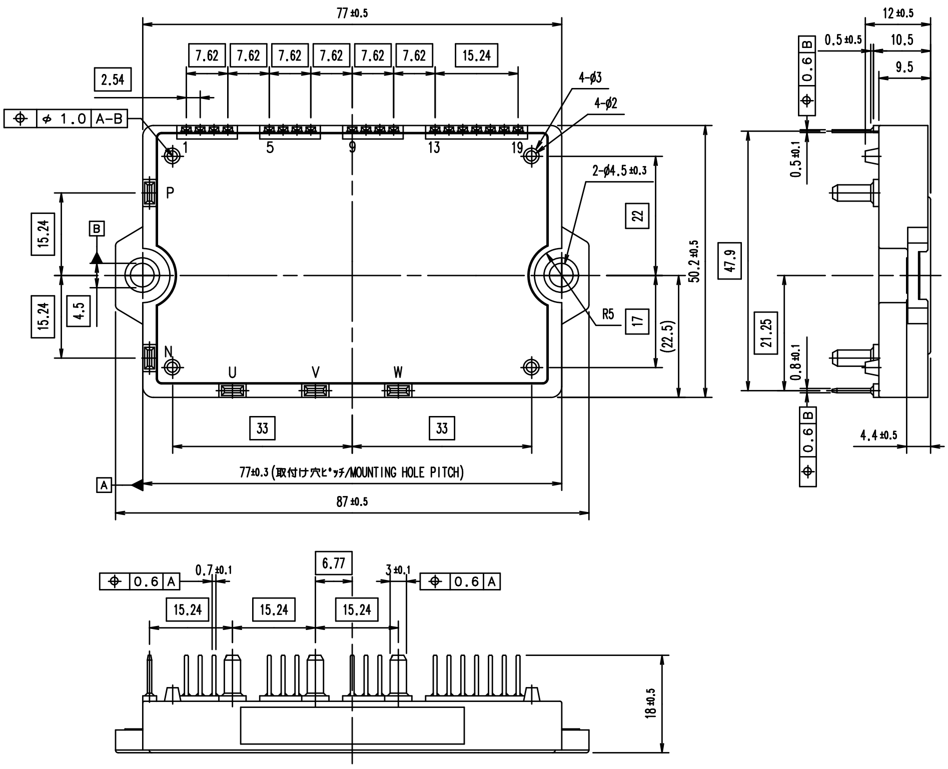
1. The dimensions shown in ☐ represent the theoretical dimension.
2. The terminal pitch is the value at the root of the terminal.
3. Dimensions in ( ) are given only for reference.
4. Terminal plating: Sn (for soldering)

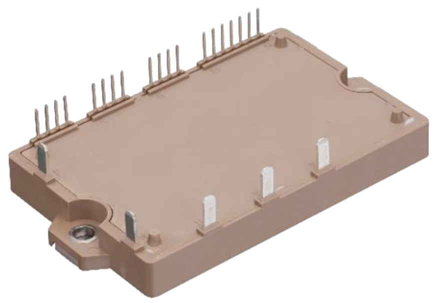
[Unit of dimensions : mm]

Fig.1-3 Package outline drawing(P629)

4.3 P626 package (6in1 with upper and lower arm alarm signal output)

- The line-up is 50A to 100A for 650V and 25A to 50A for 1200V.
- Terminal pitch of the control terminals is standard 2.54 mm.
- Main terminals are flat type solder pin and the height is the same as the control terminals.
  Therefore, it is possible to solder the main terminals and control terminals to the same PCB.
- Screw size for the heat sink is M4.
- The package outline drawing is shown in Figure 1-4.





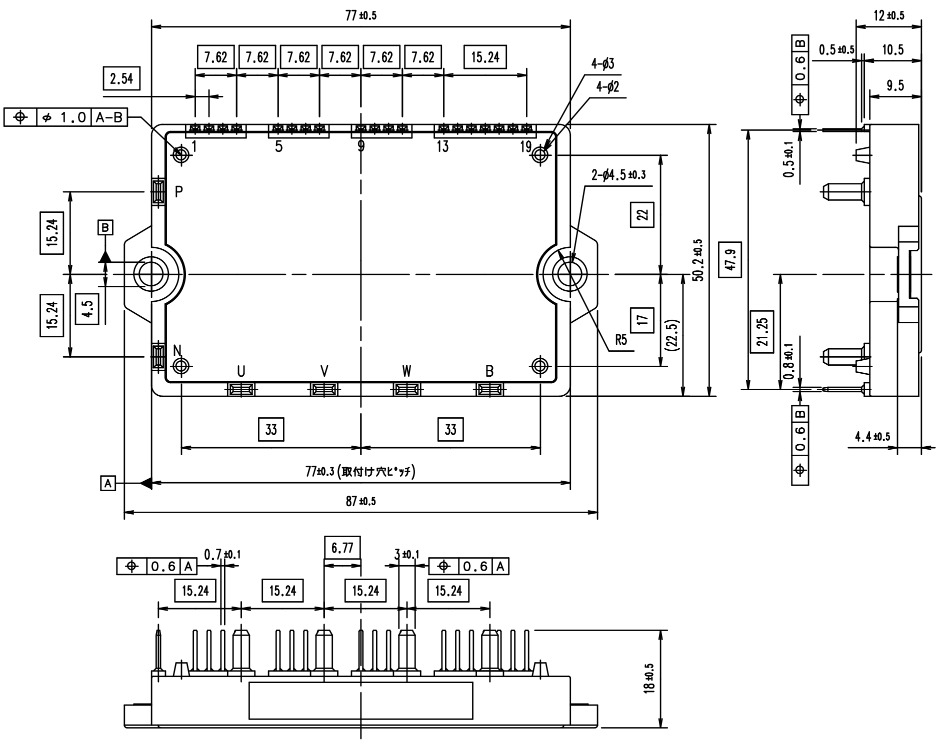
Note:
1. The dimensions shown in ☐ represent the theoretical dimension.
2. The terminal pitch is the value at the root of the terminal.
3. Dimensions in ( ) are given only for reference.
4. Terminal plating: Sn (for soldering)

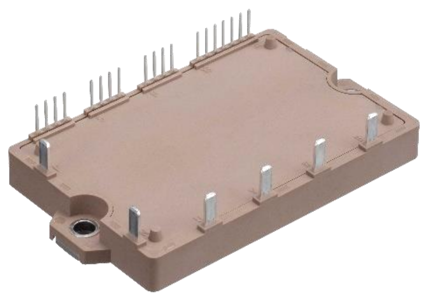
[Unit of dimensions: mm]

Fig.1-4 Package outline drawing (P626)

4.4 P644 package (7in1 with upper and lower arm alarm signal output)

- The line-up is 50A to 75A for 650V and 25A to 35A for 1200V.
- Terminal pitch of the control terminals is standard 2.54 mm.
- Main terminals are flat type solder pin and the height is the same as the control terminals. Therefore, it is possible to solder the main terminals and control terminals to the same PCB.
- Screw size for the heat sink is M4.
- The package outline drawing is shown in Figure 1-5.





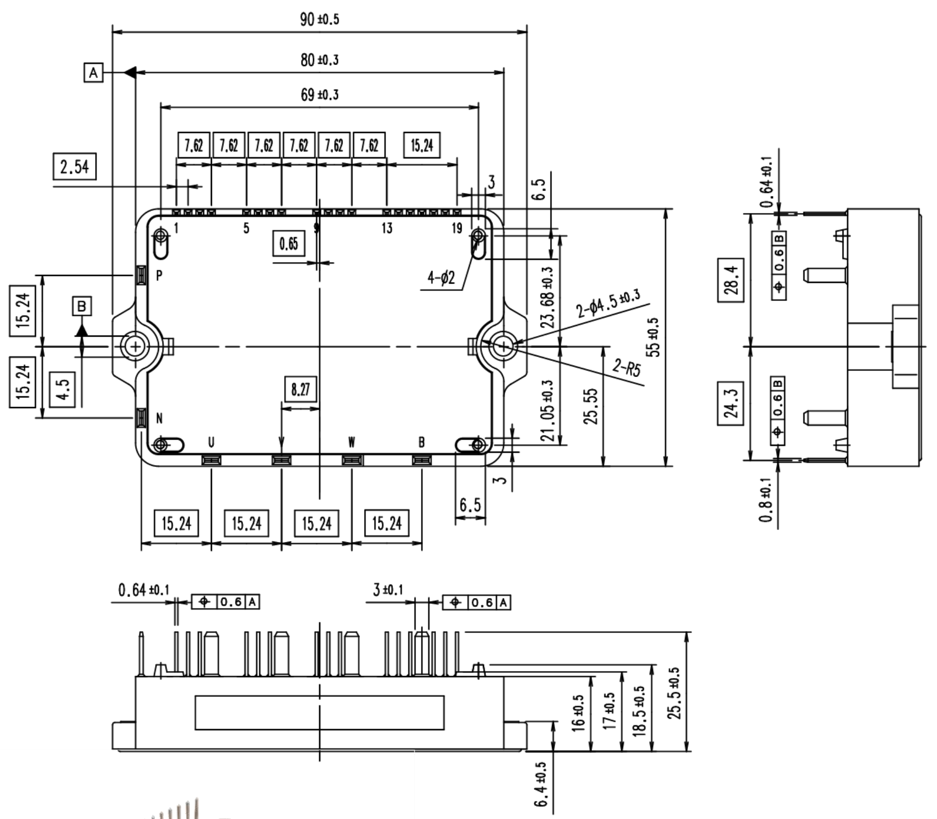
Note:
1. The dimensions shown in ☐ represent the theoretical dimension.
2. The terminal pitch is the value at the root of the terminal.
3. Dimensions in ( ) are given only for reference.
4. Terminal plating: Sn (for soldering)

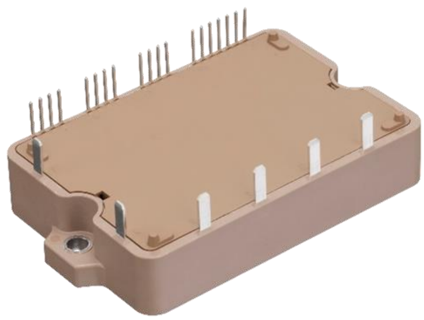
[Unit of dimensions: mm]

Fig.1-5 Package outline drawing (P644)

4.5 P636 package (6in1/7in1 with upper and lower arm alarm signal output)

- The line-up is 50A to 100A for 650V and 25A to 50A for 1200V.
- Terminal pitch of the control terminals is standard 2.54 mm.
- Main terminals are flat type solder pin and the height is the same as the control terminals. Therefore, it enables to solder the main terminals and control terminals to the same PCB.
- Screw size for the heat sink is M4.
- Two types of protrusions with different heights are provided on the upper surface of the lid. The height from the base surface to the device control printed board can be selected from 17.0 mm and 18.5 mm. Refer to Figure 1-18.
- The package outline drawing is shown in Figure 1-6.





Note:

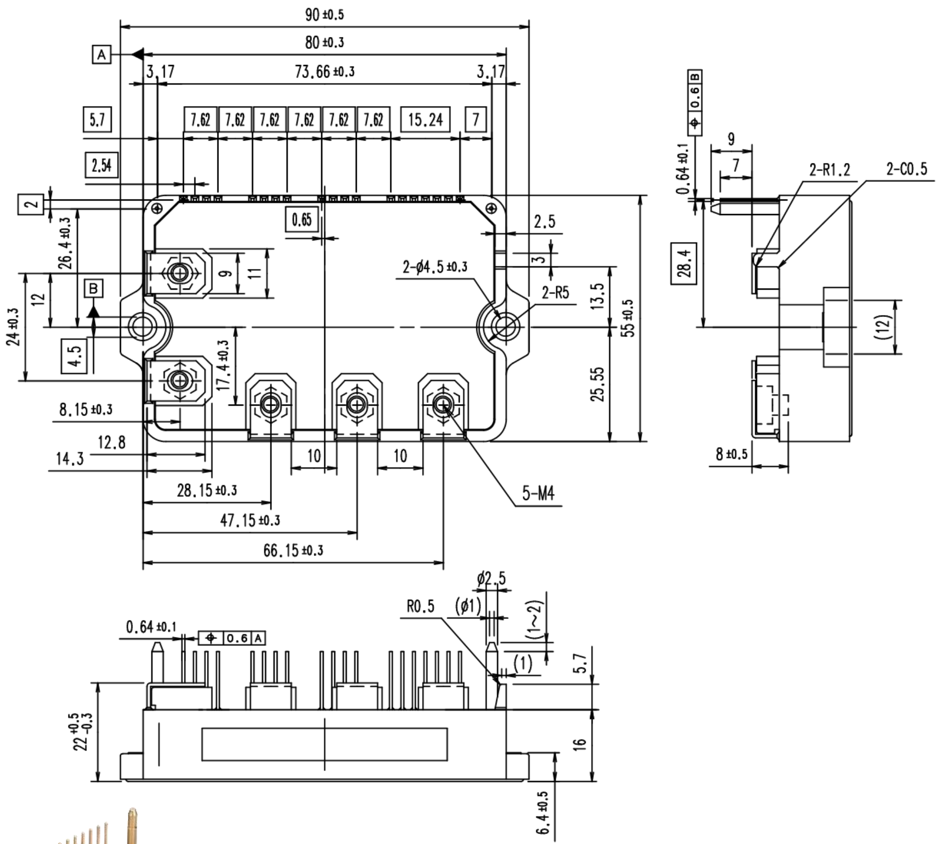
1. The dimensions shown in ☐ represent the theoretical dimension.
2. The terminal pitch is the value at the root of the terminal.
3. Dimensions in ( ) are given only for reference.
4. Terminal plating: Sn (for soldering)

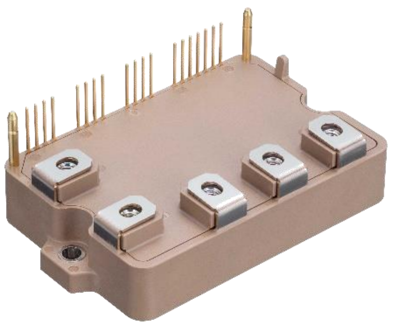
[Unit of dimensions：mm]

Fig.1-6 Package outline drawing(P636)

4.6 P638 package (6in1 with upper and lower arm alarm signal output)

- The line-up is 50A to 150A for 650V and 25A to 75A for 1200V.
- Terminal pitch of the control terminals is standard 2.54 mm and can be connected with general-purpose connectors and soldering.
  Guide pins make it easy to insert connectors for printed circuit boards.
- Main terminals are M4 screws.
- Screw size for the heat sink is M4 common with the main terminals.
- All electrical connections are done with screws and connectors, thus no soldering is required and easy to remove.
- The package outline drawing is shown in Figure 1-7.





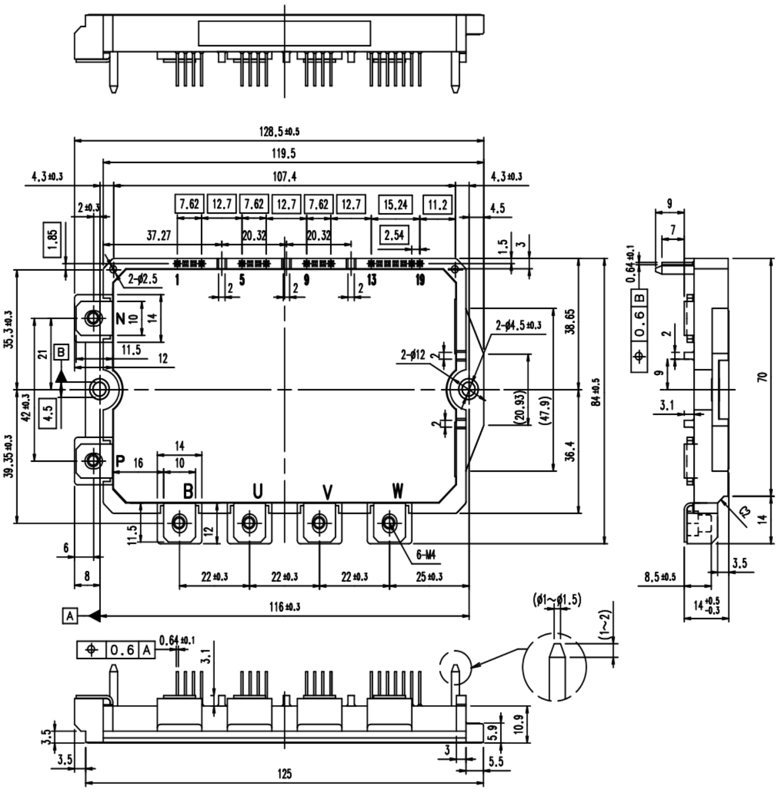
Note:
1. The dimensions shown in ☐ represent the theoretical dimension.
2. The terminal pitch is the value at the root of the terminal.
3. Dimensions in ( ) are given only for reference.
4. Main terminal plating: Ni
   Control terminal plating: Ni plating on the ground, Au plating on the surface. (for connector and soldering use)
5. The guide pins located on both sides of a control terminal are made of brass.
   (They are insulated internally and are not connected to any object.)

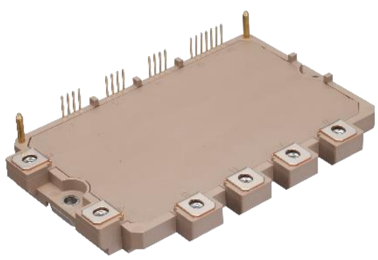
[Unit of dimensions : mm]

Fig.1-7 Package outline drawing (P638)

4.7 P630 package (6in1/7in1 with upper and lower arm alarm signal output)

- The line-up is 50A to 250A for 650V and 25A to 150A for 1200V.
- Terminal pitch of the control terminals is standard 2.54 mm and can be connected with general-purpose connectors and soldering.
  Guide pins make it easy to insert connectors for printed circuit boards.
- Main terminals are M4 screws.
- Screw size for the heat sink is M4 common with the main terminals.
- All electrical connections are done with screws and connectors, thus no soldering is required and easy to remove.
- The package outline drawing is shown in Figure 1-8.





Note:

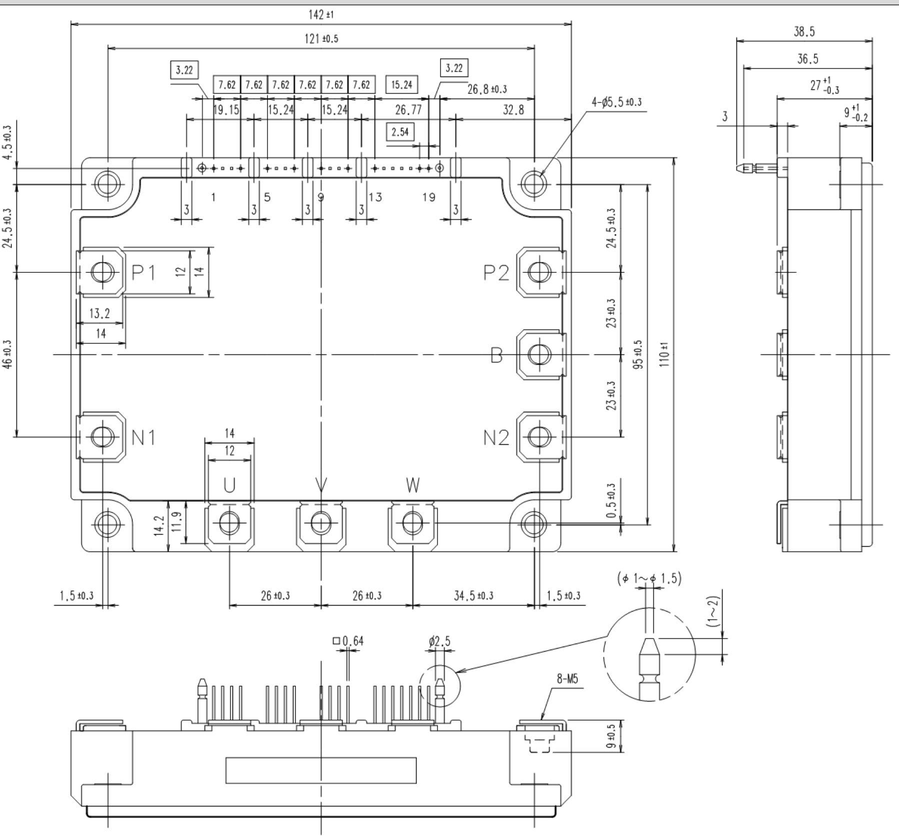
1. The dimensions shown in ☐ represent the theoretical dimension.
2. The terminal pitch is the value at the root of the terminal.
3. Dimensions in ( ) are given only for reference.
4. Main terminal plating: Ni
   Control terminal plating: Ni plating on the ground, Au plating on the surface. (for connector and soldering use)
5. The guide pins located on both sides of a control terminal are made of brass.
   (They are insulated internally and are not connected to any object.)

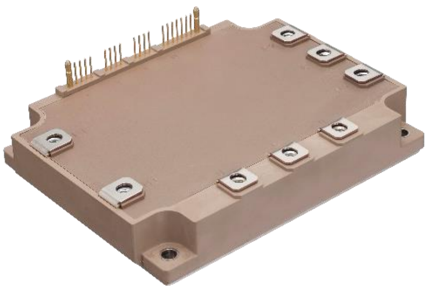
[Unit of dimensions：mm]

Fig.1-8 Package outline drawing (P630)

4.8 P631 package (6in1/7in1 with upper and lower arm alarm signal output)

- The line-up is 200A to 450A for 650V and 100A to 300A for 1200V.
- Terminal pitch of the control terminals is standard 2.54 mm and can be connected with general-purpose connectors and soldering.
- The main power input (P1, P2, N1, N2), brake input (B), and output terminals (U, V, W) are located close to each other, making main wiring easy. The P1 and P2, N1 and N2 terminals are internally connected.
- The main terminals are M5 screws, allowing high current connections to be made securely.
- Screw size for the heat sink is M5 common with the main terminals.
- All electrical connections are done with screws and connectors, thus no soldering is required and easy to remove.
- Compatible with R-IPM series P612. (Excluding the control terminal part)
- The package outline drawing is shown in Figure 1-9.





Note:

1. The dimensions shown in ☐ represent the theoretical dimension.
2. The terminal pitch is the value at the root of the terminal.
3. Dimensions in ( ) are given only for reference.
4. Main terminal plating: Ni
   Control terminal plating: Ni plating on the ground, Au plating on the surface. (for connector and soldering use)
5. The guide pins located on both sides of a control terminal are made of brass.

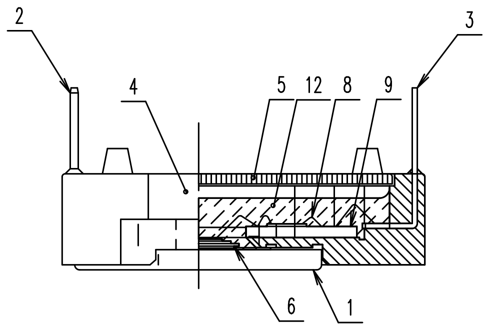
(They are insulated internally and are not connected to any object.)

[Unit of dimensions : mm]

Fig.1-9 Package outline drawing (P631)

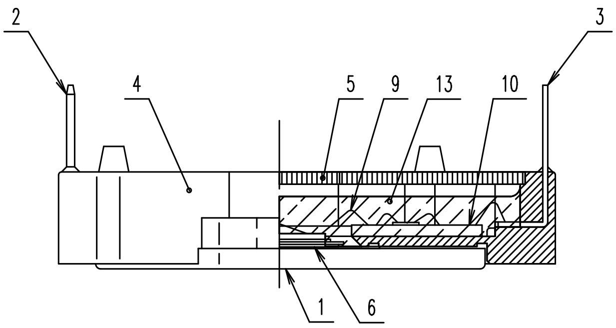
5. Structure

The structural components for each package are shown in Figure 1-10 to Figure 1-16.
* These figures are for material explanation only and do not show the exact dimensions or layout.
In addition, they do not indicate all the parts used in the products.



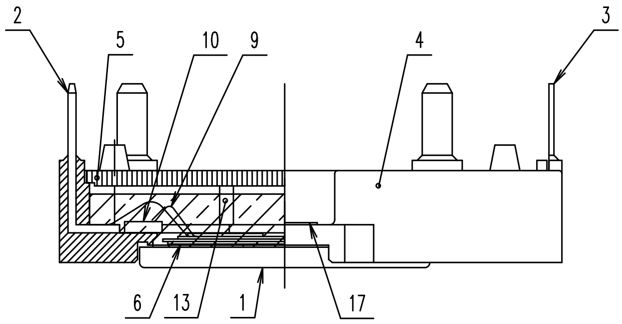
No.	Component	Material (main)	Remarks
1	Base Plate	Cu	Ni plating
2	Main Terminal	Cu	First coating : Ni plating Surface : Sn-based plating
3	Control Terminal	Brass	First coating : Ni plating Surface : Sn-based plating
4	Case	PPS resin	UL 94V-0
5	Lid	PPS resin	UL 94V-0
6	Isolation substrate	Ceramic + Cu	
7	RC-IGBT chip	Silicon	(Not shown)
8	Wiring	Aluminum	
9	Printed Circuit Board (PCB)	Glass reinforced Epoxy resin	Halogen Free
10	IC chip	Silicon	(Not shown)
11	Capacitor chip	Ceramic	Ni-Sn plating (Not shown)
12	Silicone Gel	Silicone resin	
13	Adhesive (Case, Base Plate)	Silicone resin	(Not shown)
14	Adhesive (PCB)	Epoxy resin	(Not shown)
15	Solder	Sn base (Pb free)	(Not shown)

Fig.1-10 Structure and materials (P639)



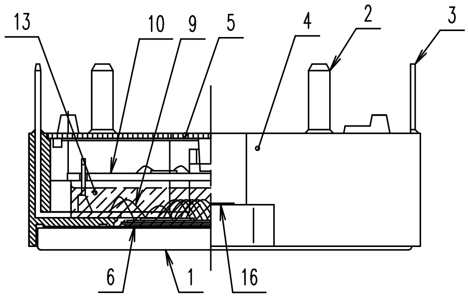
No.	Component	Material (main)	Remarks
1	Base Plate	Cu	Ni plating
2	Main Terminal	Cu	First coating : Ni plating Surface : Sn-based plating
3	Control Terminal	Brass	First coating : Ni plating Surface : Sn-based plating
4	Case	PPS resin	UL 94V-0
5	Lid	PPS resin	UL 94V-0
6	Isolation substrate	Ceramic + Cu	
7	IGBT chip	Silicon	(Not shown)
8	FWD chip	Silicon	(Not shown)
9	Wiring	Aluminum	
10	Printed Circuit Board (PCB)	Glass reinforced Epoxy resin	Halogen Free
11	IC chip	Silicon	(Not shown)
12	Capacitor chip	Ceramic	Ni-Sn plating (Not shown)
13	Silicone Gel	Silicone resin	
14	Adhesive (Case, Base Plate)	Silicone resin	(Not shown)
15	Adhesive (PCB)	Epoxy resin	(Not shown)
16	Solder	Sn base (Pb free)	(Not shown)

Fig.1-11 Structure and materials (P629)



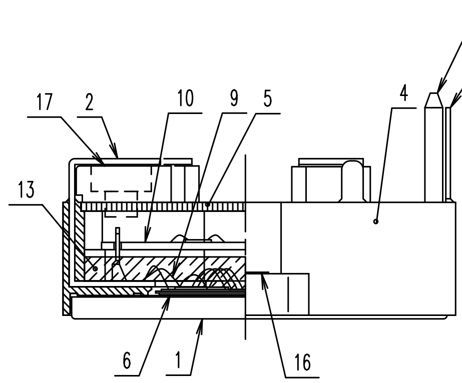
No.	Component	Material (main)	Remarks
1	Base Plate	Cu	Ni plating
2	Main Terminal	Cu	First coating : Ni plating Surface : Sn-based plating
3	Control Terminal	Brass	First coating : Ni plating Surface : Sn-based plating
4	Case	PPS resin	UL 94V-0
5	Lid	PPS resin	UL 94V-0
6	Isolation substrate	Ceramic + Cu	
7	IGBT chip	Silicon	(Not shown)
8	FWD chip	Silicon	(Not shown)
9	Wiring	Aluminum	
10	Printed Circuit Board (PCB)	Glass reinforced Epoxy resin	Halogen Free
11	IC chip	Silicon	(Not shown)
12	Capacitor chip	Ceramic	Ni-Sn plating (Not shown)
13	Silicone Gel	Silicone resin	
14	Adhesive (Case, Base Plate)	Silicone resin	(Not shown)
15	Adhesive (PCB)	Epoxy resin	(Not shown)
16	Solder	Sn base (Pb free)	(Not shown)
17	Ring	Stainless steel	

Fig.1-12 Structure and materials (P626, P644)



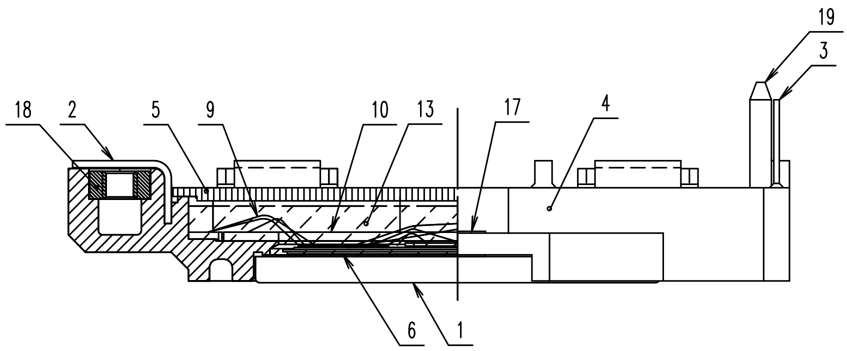
No.	Component	Material (main)	Remarks
1	Base Plate	Cu	Ni plating
2	Main Terminal	Cu	First coating : Ni plating Surface : Sn-based plating
3	Control Terminal	Brass	First coating : Ni plating Surface : Sn-based plating
4	Case	PPS resin	UL 94V-0
5	Lid	PPS resin	UL 94V-0
6	Isolation substrate	Ceramic + Cu	
7	IGBT chip	Silicon	(Not shown)
8	FWD chip	Silicon	(Not shown)
9	Wiring	Aluminum	
10	Printed Circuit Board (PCB)	Glass reinforced Epoxy resin	Halogen Free
11	IC chip	Silicon	(Not shown)
12	Capacitor chip	Ceramic	Ni-Sn plating (Not shown)
13	Silicone Gel	Silicone resin	
14	Adhesive (Case, Base Plate)	Silicone resin	(Not shown)
15	Solder	Sn base (Pb free)	(Not shown)
16	Ring	Stainless steel	

Fig.1-13 Structure and materials (P636)



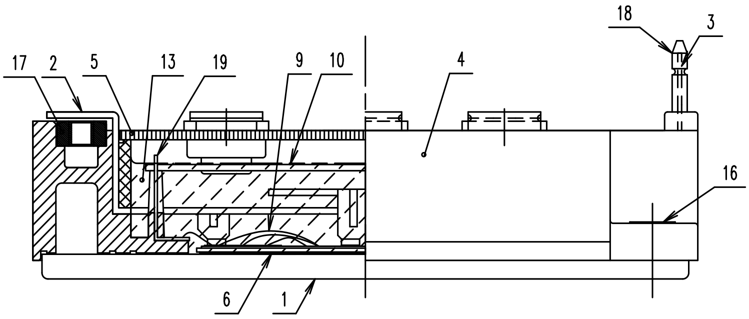
No.	Component	Material (main)	Remarks
1	Base Plate	Cu	Ni plating
2	Main Terminal	Cu	Ni plating
3	Control Terminal	Brass	First coating : Ni plating Surface : Au plating
4	Case	PPS resin	UL 94V-0
5	Lid	PPS resin	UL 94V-0
6	Isolation substrate	Ceramic + Cu	
7	IGBT chip	Silicon	(Not shown)
8	FWD chip	Silicon	(Not shown)
9	Wiring	Aluminum	
10	Printed Circuit Board (PCB)	Glass reinforced Epoxy resin	Halogen Free
11	IC chip	Silicon	(Not shown)
12	Capacitor chip	Ceramic	Ni-Sn plating (Not shown)
13	Silicone Gel	Silicone resin	
14	Adhesive (Case, Base Plate)	Silicone resin	(Not shown)
15	Solder	Sn base (Pb free)	(Not shown)
16	Ring	Stainless steel	
17	Nut	Fe	Trivalent chromate treatment
18	Guide pin	Brass	

Fig.1-14 Structure and materials (P638)



No.	Component	Material (main)	Remarks
1	Base Plate	Cu	Ni plating
2	Main Terminal	Cu	Ni plating
3	Control Terminal	Brass	First coating : Ni plating Surface : Au plating
4	Case	PPS resin	UL 94V-0
5	Lid	PPS resin	UL 94V-0
6	Isolation substrate	Ceramic + Cu	
7	IGBT chip	Silicon	(Not shown)
8	FWD chip	Silicon	(Not shown)
9	Wiring	Aluminum	
10	Printed Circuit Board (PCB)	Glass reinforced Epoxy resin	Halogen Free
11	IC chip	Silicon	(Not shown)
12	Capacitor chip	Ceramic	Ni-Sn plating (Not shown)
13	Silicone Gel	Silicone resin	
14	Adhesive (Case, Base Plate)	Silicone resin	(Not shown)
15	Adhesive (PCB)	Epoxy resin	(Not shown)
16	Solder	Sn base (Pb free)	(Not shown)
17	Ring	Stainless steel	
18	Nut	Fe	Trivalent chromate treatment
19	Guide pin	Brass	

Fig.1-15 Structure and materials (P630)



No.	Component	Material (main)	Remarks
1	Base Plate	Cu	Ni plating
2	Main Terminal	Cu	Ni plating
3	Control Terminal	Brass	First coating : Ni plating Surface : Au plating
4	Case	PPS resin	UL 94V-0
5	Lid	PPS resin	UL 94V-0
6	Isolation substrate	Ceramic + Cu	
7	IGBT chip	Silicon	(Not shown)
8	FWD chip	Silicon	(Not shown)
9	Wiring	Aluminum	
10	Printed Circuit Board (PCB)	Glass reinforced Epoxy resin	Halogen Free
11	IC chip	Silicon	(Not shown)
12	Capacitor chip	Ceramic	Ni-Sn plating (Not shown)
13	Silicone Gel	Silicone resin	
14	Adhesive (Case, Base Plate)	Silicone resin	(Not shown)
15	Solder	Sn base (Pb free)	(Not shown)
16	Ring	Stainless steel	
17	Nut	Fe	Trivalent chromate treatment
18	Guide pin	Brass	
19	Internal Terminal	Brass	Ni plating

Fig.1-16 Structure and materials (P631)

• Main terminals of IPM (screw type)
The structure of the main terminal is shown in Figure 1-17:

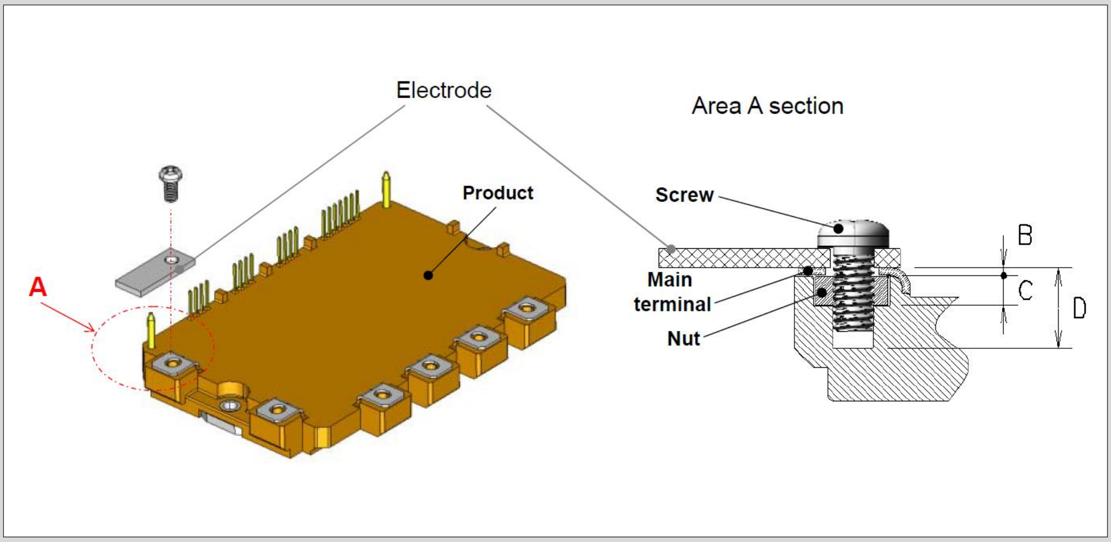


Fig.1-17 IPM main terminal structure (Example: P630)

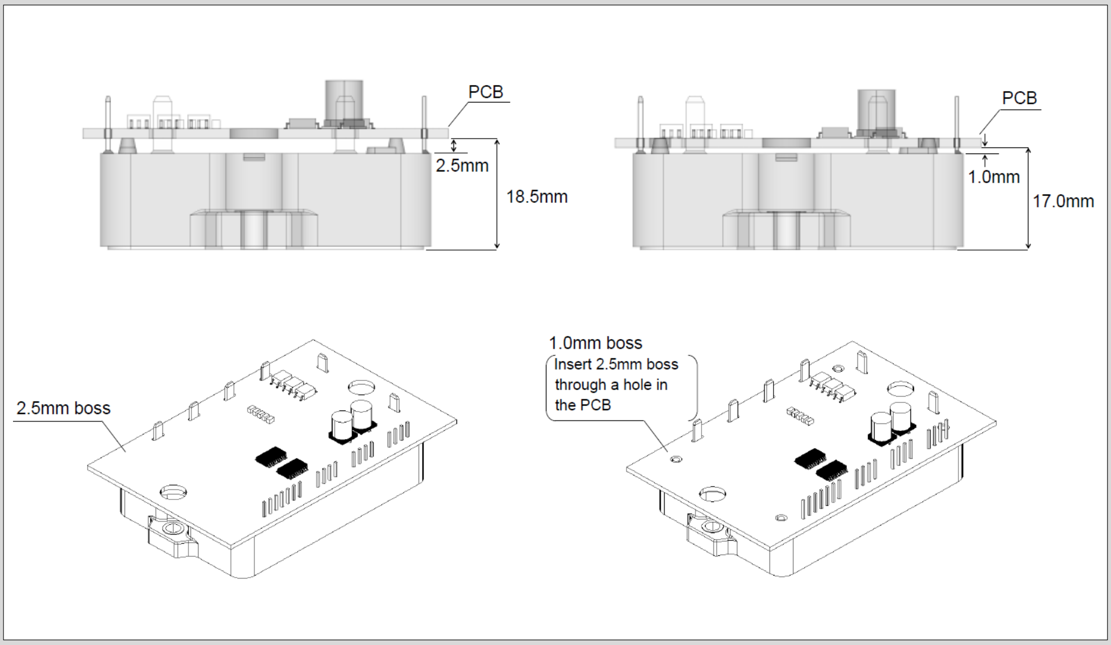
Table 1-5 IPM main terminal specifications

Package	Screw standard	Terminal tab thickness (B)	Nut depth (C)	Screw hole depth (D)
P638	M4	0.8	3.5	8.0 ± 0.5
P630	M4	0.8	3.5	8.5 ± 0.5
P631	M5	1	4	9.0 ± 0.5

[Unit : mm]

• Guide pins of IPM
The guide pins located on both sides of control terminal portions of P638, P630 and P631 are made of brass. They are insulated internally and are not connected to any object.

• Height of the protrusion on lid of P636
P636 package has two types of protrusions with different heights (2.5 mm and 1.0 mm) on the lid.
The PCB height can be set to 18.5 mm or 17.0 mm by utilizing these protrusions.



(a) When the height is 18.5mm (b) When the height is 17.0mm

Fig.1-18 Selecting from two different protrusion heights

Chapter 2 Description of terminal marking and terms

This chapter describes the terminal marking and terms of the X series IPM.

1. Description of terminal marking

1.1 Main terminals

Terminal name	Description
P (P1, P2) N (N1, N2)	V_{DC} input terminals after smoothing capacitor P: + side, N: - side
B	Collector terminal of the Brake IGBT. Connect a brake resistor for dissipating regenerative energy
U V W	3-phase output terminals

* P1, P2, N1 and N2 terminals are available in P631 package only.

1.2 Control terminals

Terminal name		P639 P629	P626,P644 P630, P636,P638	P631	Description
GND V_{CC}	U U	① ③	① ④	① ③	Ground reference for the U-arm control power supply U-arm control power supply positive terminal
V_{in}	U	②	③	②	U-arm control signal input
ALM	U	—	②	④	U-arm alarm signal output
GND V_{CC}	V V	④ ⑥	⑤ ⑧	⑤ ⑦	Ground reference for the V-phase control power supply V-arm control power supply positive terminal
V_{in}	V	⑤	⑦	⑥	V-arm control signal input
ALM	V	—	⑥	⑧	V-arm alarm signal output
GND V_{CC}	W W	⑦ ⑨	⑨ ⑫	⑨ ⑪	Ground reference for the W-phase control power supply W-arm control power supply positive terminal
V_{in}	W	⑧	⑪	⑩	W-arm control signal input
ALM	W	—	⑩	⑫	W-arm alarm signal output
GND V_{CC}		⑩ ⑪	⑬ ⑭	⑬ ⑭	Ground reference for the lower arms control power supply Control power supply positive terminal for the lower arms
V_{in}	X	⑫	⑯	⑯	X-arm control signal input
V_{in}	Y	⑬	⑰	⑰	Y-arm control signal input
V_{in}	Z	⑭	⑱	⑱	Z-arm control signal input
V_{in}	DB	—	⑮	⑮	DB-arm control signal input
WNG					T_{vj} warning signal output for IGBT (Y)
ALM		⑮	⑲	⑲	Lower-arm alarm signal output

* Pin (15) of P626 and P638 is WNG.
* Pin (15) of P636(6in1), P630(6in1) and P631(6in1) is WNG.

2. Description of terms

2.1 Absolute maximum rating

Term		Symbol	Description
DC power supply voltage		V_{DC}	Maximum DC bus voltage between the P and N terminal
DC power supply voltage at short circuit		V_{SC}	Maximum DC bus voltage between the P and N terminal during short-circuit protection and over current protection
Collector-Emitter voltage		V_{CES}	Maximum voltage between the collector and emitter terminal of the built-in IGBT, and peak inverse voltage of the FWD.
Collector current		I_C	Maximum DC collector current for each IGBT
		I_{CP}	Maximum peak collector current for each IGBT
		$-I_C$	Maximum DC forward current for each FWD
Diode forward current for DB		I_F	Maximum DC forward current for FWD in brake circuit
Total power dissipation		P_{tot}	Maximum power dissipation for each IGBT at T_c=25°C, T_{vj}=175°C
Supply voltage of pre-driver		V_{CC}	Maximum voltage between the V_{CC} and GND terminal
Input signal voltage		V_{in}	Maximum voltage between the V_{in} and GND terminal
Alarm signal voltage		V_{ALM}	Maximum voltage between the ALM and GND terminal
Alarm signal current		I_{ALM}	Maximum current between the ALM and GND terminal
T_{vj} warning signal voltage		V_{WNG}	Maximum voltage between the WNG and GND terminal
T_{vj} warning signal current		I_{WNG}	Maximum current between the WNG and GND terminal
Virtual junction temperature		T_{vj}	Junction temperature of IGBT and FWD
Operating virtual junction temperature		T_{vjop}	Junction temperature at which IGBT and FWD can operate continuously
Operating case temperature		T_{cop}	Allowable case temperature during switching operation (measured point of the case temperature T_c is shown in Figure 5-4)
Storage temperature		T_{stg}	Allowable ambient temperature during storage without being subject to electrical load.
Solder temperature		T_{sol}	Maximum temperature for soldering the terminals to a PCB
Isolation voltage		V_{isol}	Maximum RMS sinusoidal voltage between all the terminals and heat sink (all terminals are shorted)
Screw torque	Terminal	M_t	Maximum screw torque when connecting the main terminal and external wiring with specified screw
	Mounting	M_s	Maximum screw torque when mounting the IPM on heat sink with specified screw

2.2 Electrical characteristics

2.2.1 Main circuit

Term	Symbol	Description
Collector Current at off signal input	I_{CES}	Leakage current when specified voltage is applied between the collector and emitter and all input signals are "H" (=all IGBTs are turned-off).
Collector-Emitter saturation voltage	$V_{CE(sat)}$	Voltage drop between the collector and emitter when gate input signal is "L"(=IGBT is turned-on).
Forward voltage of FWD	V_F	Voltage drop across the FWD at defined forward current at input signal is "H" (=IGBT is turned of).
Turn-on time	t_{on}	The time from when the input signal drop below the input threshold value $V_{inth(on)}$ until the collector current of IGBT become above 90% of predetermined current. Refer to Figure 2-1.(page 2-7)
	$t_{d(on)}$	The time from when the input signal drop below the input threshold value $V_{inth(on)}$ until the collector current of IGBT become above 10% of predetermined current. Refer to Figure 2-1.
Turn-off time	t_{off}	The time from when the input signal rise above the input threshold value $V_{inth(off)}$ until the collector current of IGBT become 10% of predetermined current. Refer to Figure 2-1.
	$t_{d(off)}$	The time from when the input signal rise above the input threshold value $V_{inth(off)}$ until the collector current of IGBT become 90% of predetermined current. Refer to Figure 2-1.
Fall time	t_f	The time for the collector current to decrease from 90% to 10% of the load current. Refer to Figure 2-1.
Reverse recovery time	t_{rr}	The time required for the reverse recovery current of the FWD to disappear on the tangent line where it decreases. Refer to Figure 2-1.
Dead time	t_{dead}	On-off timing delay between upper and lower arm. Refer to Figure 2-6.

2.2.2 Control circuit

Term	Symbol	Description
Supply current of pre-driver	I_{ccp}	Current flows between V_{CC} terminal and GND of upper arm control power supply
	I_{ccn}	Current flows between V_{CC} terminal and GND of lower arm control power supply
Input signal threshold voltage	$V_{inth(on)}$	Input voltage which IPM can detect as ON signal.
	$V_{inth(off)}$	Input voltage which IPM can detect as OFF signal.

2.2.3 Protection circuit

Term	Symbol	Description
Over current protection level	I_{OC}	Threshold current for overcurrent protection
Over current protection delay time	t_{dOC}	Delay time from exceeding the over current protection trip level until the protection starts. Refer to Figure 2-4.
Short circuit protection operating current	I_{SC}	Threshold current for short-circuit protection
Short circuit protection delay time	t_{dSC}	Delay time from exceeding the short-circuit protection trip level until the protection starts. Refer to Figure 2-5.
IGBT chips over heating protection temperature level	T_{jOH}	Threshold junction temperature for over heating protection.
Over heating protection hysteresis	T_{jH}	Temperature drop required for over heating protection to reset.
IGBT chips warning temperature level	T_{jW}	IGBT chips temperature at which chips warning temperature signal is output.
Warning hysteresis	T_{jWH}	Temperature drop required for chips warning temperature operation to reset.
Under voltage protection level	V_{uv}	Threshold voltage for under voltage protection.
Under voltage protection hysteresis	V_H	Voltage that must exceed for under voltage protection to reset.
Alarm signal hold time	$t_{ALM(OC)}$	Alarm signal pulse width for overcurrent protection (OC)
	$t_{ALM(UV)}$	Alarm signal pulse width for under voltage protection (UV)
	$t_{ALM(TjOH)}$	Alarm signal pulse width for IGBT chips over heating protection (T_{jOH})
Warning signal hold time	t_{WNG}	Warning signal output time during chip temperature warning operation
Alarm signal voltage	V_{ALMH}	Alarm terminal voltage when protection is not operating
Warning signal Voltage	V_{WNGH}	Warning terminal voltage when chip temperature warning is not operating.
Alarm output resistance	R_{ALM}	Value of the built-in resistance that is connected in series to alarm terminals. It limits the primary side forward current of optocoupler.
Warning output resistance	R_{WNG}	Value of the built-in resistance that is connected in series to warning terminals. It limits the primary side forward current of optocoupler.

2.3 Thermal characteristics

Term	Symbol	Description
Thermal resistance between junction and case	$R_{th(j-c)Q}$	Thermal resistance between the case and IGBT junction.
	$R_{th(j-c)D}$	Thermal resistance between the case and FWD junction.
Thermal resistance between case and heat sink	$R_{th(c-s)}$	Thermal resistance between the case and the heat sink, when the IPM is mounted on a heat sink with the specified torque and thermal compound.
Case temperature	T_c	IPM case temperature (Temperature of the copper base surface directly under the chip)

2.4 Noise tolerance

Term	Symbol	Description
Common mode rectangular noise	—	Common mode noise tolerance in our test circuit

2.5 Others

Term	Symbol	Description
Weight	W_t	Weight of the IPM
Switching frequency	f_{sw}	Switching frequency that can be input to the control signals input terminals.
Reverse recovery current	I_{rr}	Peak value of the reverse recovery current. Refer to Figure 2-1.
Reverse bias safe operating area	RBSOA	The area of voltage and current which the IPM can operate safely during turn-off. If used outside this area, the IPM may be destroyed.
Switching loss	E_{on}	Dissipated switching energy of the IGBT during turn-on
	E_{off}	Dissipated switching energy of the IGBT during turn-off
	E_{rr}	Dissipated switching energy of the FWD during reverse recovery
Input current	I_{in}	Maximum current into the V_{in} terminals
Soft shutdown	–	Turn-off operation when protective operation is activated. (Softer turn-off than normal)

2.6 Operation explanatory diagram

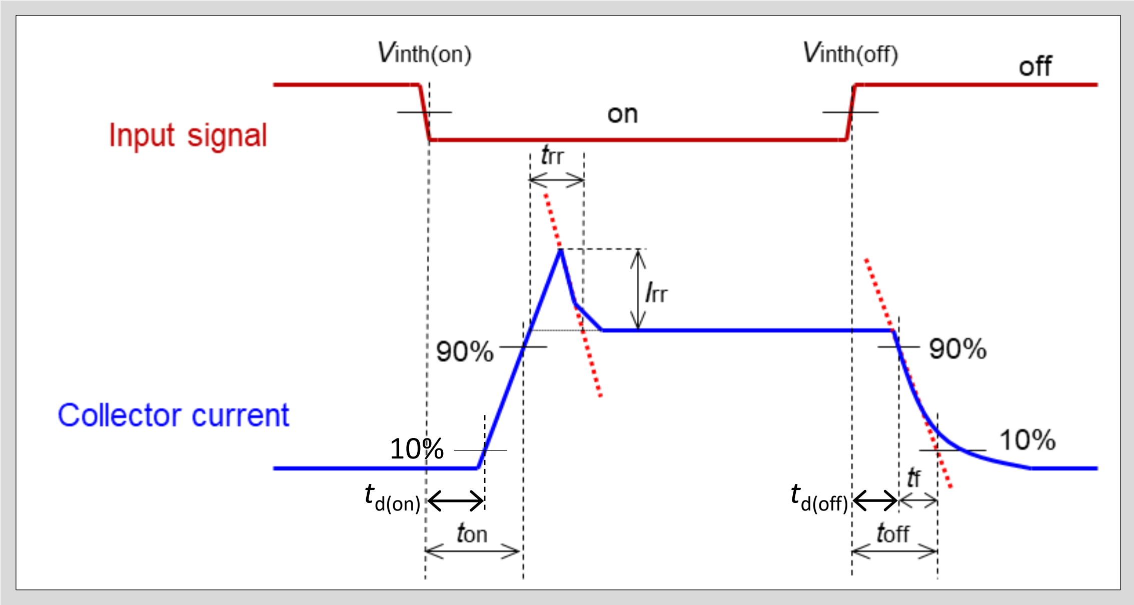


Fig.2-1 Switching times

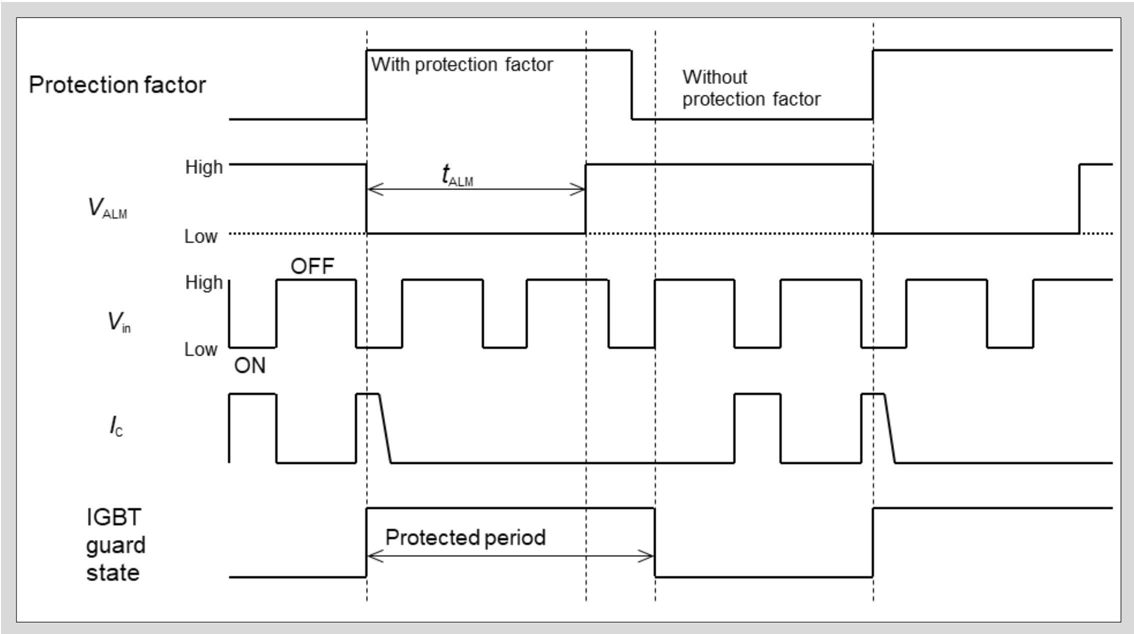


Fig.2-2 Alarm signal output hold time(t_{ALM})

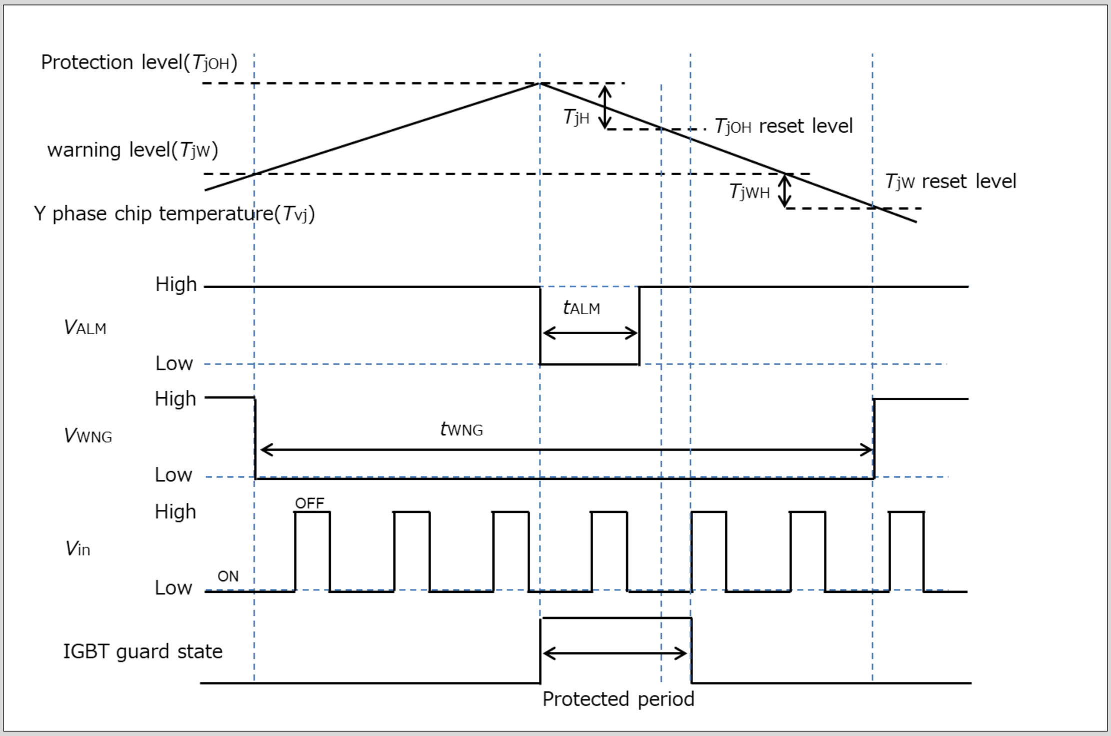


Fig.2-3 Warning Timing Diagram

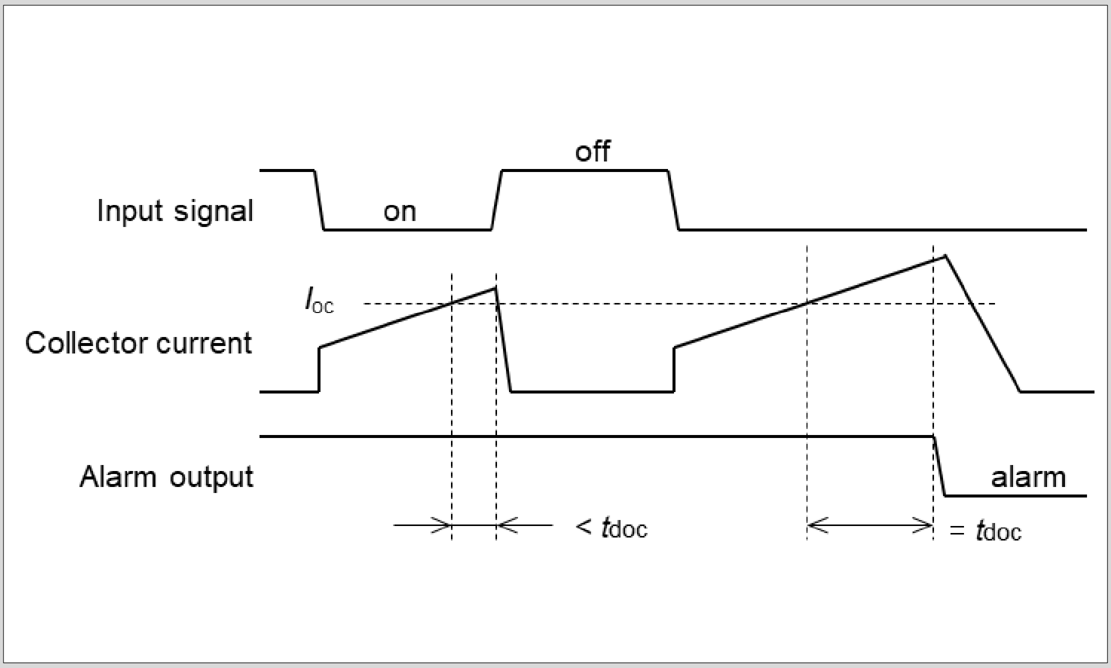


Fig.2-4 Overcurrent protection delay time(t_{dOC})

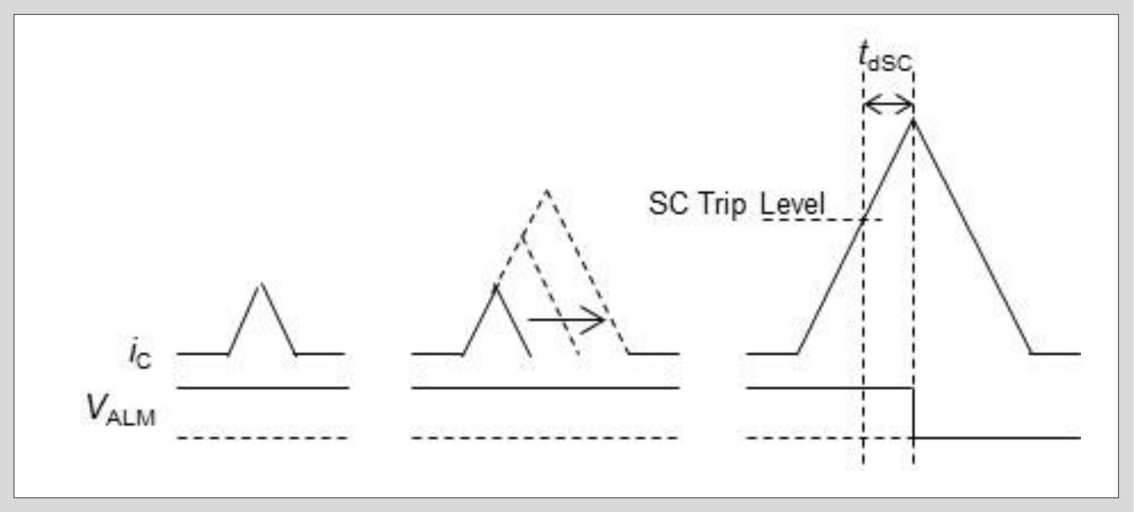


Fig.2-5 Short circuit protection delay time(t_{dSC})

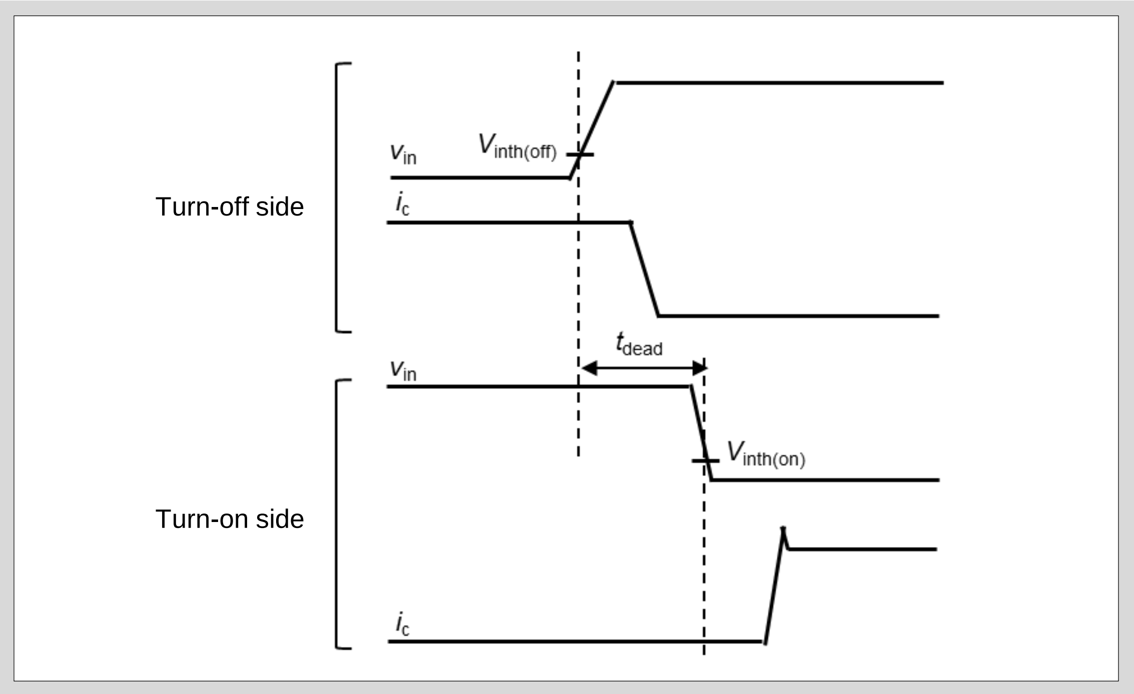


Fig.2-6 Dead time(t_{dead})

Chapter 3 Description of functions

This chapter describes the functions of the X series IPM.

1. List of functions

The built-in functions in the X series IPM are shown in Table 3-1 and 3-2.

Table 3-1 IPM built-in functions (6in1)

Number of Switch	Package	Built-in Function						
		Upper and Lower arms				Upper arm	Lower arm	
		Drive	UV	T_{jOH}	OC SC	ALM	ALM	WNG
6in1	P639	○	○	○	○	-	○	-
	P629	○	○	○	○	-	○	-
	P626	○	○	○	○	○	○	○
	P636	○	○	○	○	○	○	○
	P638	○	○	○	○	○	○	○
	P630	○	○	○	○	○	○	○
	P631	○	○	○	○	○	○	○

Drive: IGBT drive circuit, UV: Control power supply under voltage protection,
T_{jOH}: IGBT chips over heating protection, OC: Over current protection,
SC: Short circuit protection, ALM: Alarm signal output, WNG: Chip temperature warning output

Table 3-2 IPM built-in functions (7in1)

Number of Switch	Package	Built-in Function						
		Upper and Lower arms				Upper arm	Lower arm	
		Drive	UV	T_{jOH}	OC SC	ALM	ALM	WNG
7in1	P644	○	○	○	○	○	○	-
	P636	○	○	○	○	○	○	-
	P630	○	○	○	○	○	○	-
	P631	○	○	○	○	○	○	-

Drive: IGBT drive circuit, UV: Control power supply under voltage protection,
T_{jOH}: IGBT chips over heating protection, OC: Over current protection,
SC: Short circuit protection, ALM: Alarm signal output, WNG: Chip temperature warning output

2. Description of functions

2.1 IGBT and FWD for 3-phase inverter

The IPM has a 3-phase bridge circuit which consists of IGBTs and FWDs as shown in Figure 3-1. The main circuit is completed when the main DC bus power supply line is connected to the P and N terminals and the 3-phase output line is connected to the U, V and W terminals. Connect a snubber circuit to suppress the surge voltage.

2.2 IGBT and FWD for brake

IGBT and FWD for brake circuit are integrated in and the collector terminal of the IGBT is connected to the output terminal B as shown in Figure 3-1. The regenerative energy during deceleration is dissipated by the resistor which is connected between terminal P and B. Voltage rise between terminal P and N can be suppressed by switching the brake IGBT.

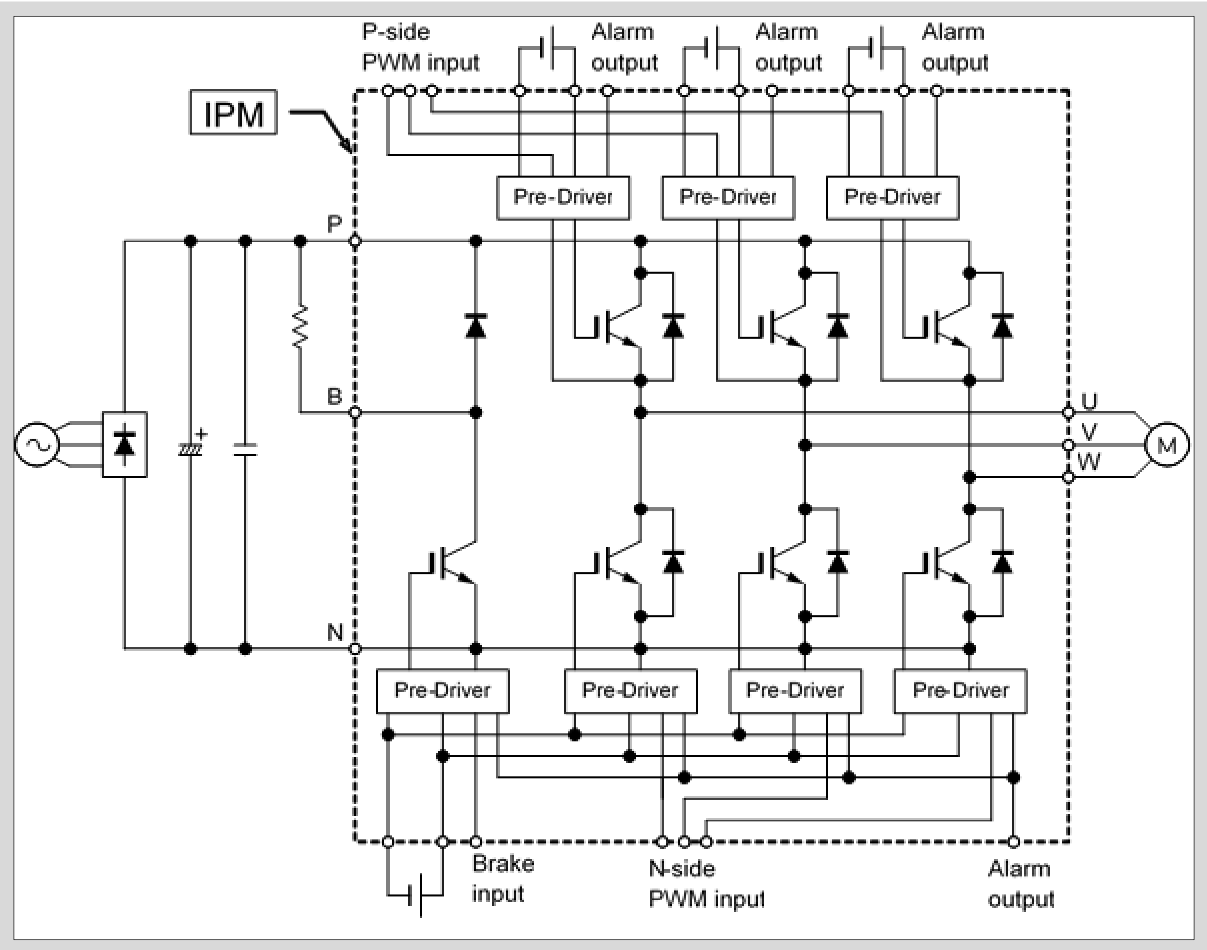


Fig.3-1 Typical application of 3-phase inverter (Example: 7MBP250XDA065-50 with built-in brake)

2.3 IGBT drive function

Figure 3-2 shows a block diagram of the Pre-Driver. The IPM has a built-in gate driving circuit for the IGBT and it is possible to drive the IGBT by providing an opto-isolated control signal to the IPM without designing a gate driving circuit.

The features of this drive function are introduced below:

- **Independent turn-on and turn-off control**
  The IPM has independent gate driving circuits for turn-on and turn-off. Therefore, the driving circuits control the dv/dt of turn-on and turn-off independently and maximize the performance of the device.

- **Soft shutdown**
  The gate voltage is gradually reduced when the IGBT is turned-off by the protection function in various kinds of abnormal modes. This soft shutdown suppresses the surge voltage during turn-off and prevents the IPM from being destroyed.

- **Prevention of false turn-on**
  The gate terminal of the IGBT is connected to the grounded emitter with low impedance. It prevents false turn-on of the IGBT due to V_{GE} rising resulting from noise or other cause.

- **No reverse bias power supply is necessary**
  Since the wiring length between the control IC and the IGBT in the IPM are short, the wiring impedance is small. Therefore, the IPM can be driven without reverse bias.

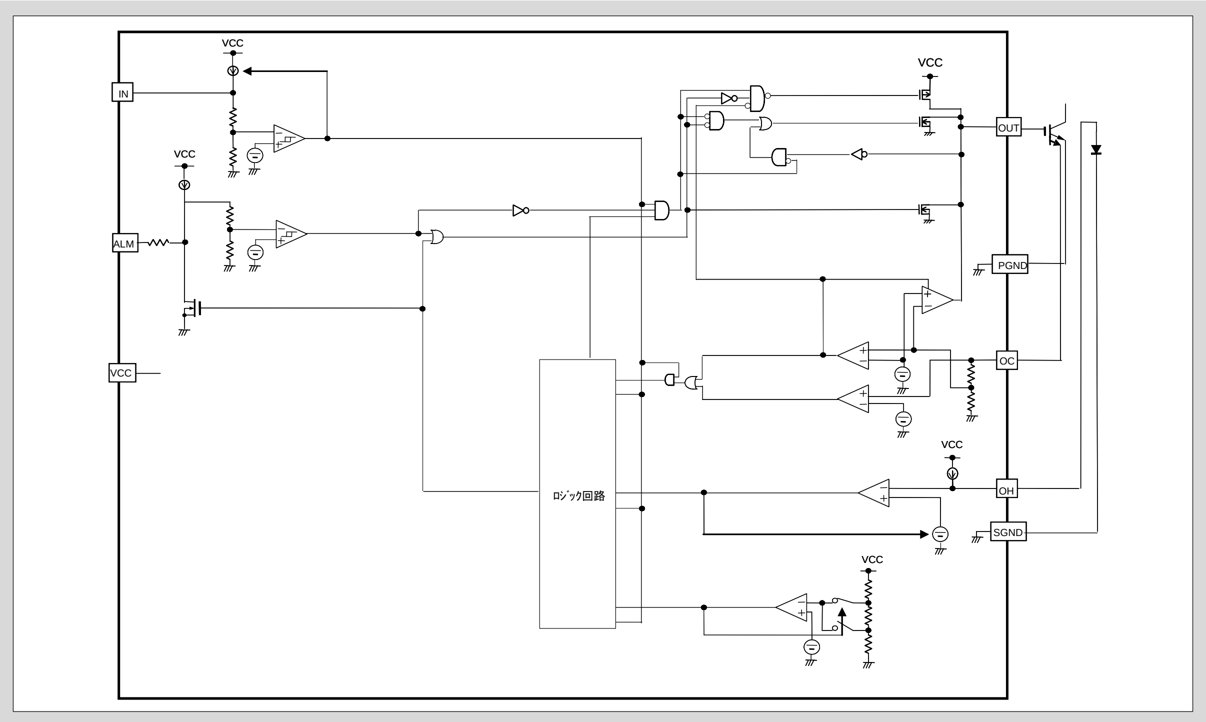


Fig.3-2 Pre-Driver block diagram (Example:7MBP250XDA065-50)

2.4 Protection functions

The IPM has protection circuits that protects the IPM from abnormal modes. The IPM has four types of protection functions; OC (over current protection), SC (short circuit protection), UV(control power supply under voltage protection) and T_{jOH} (IGBT chips over heating protection).

When a protective function is activated, the MOSFET for alarm output is turned on, the alarm output signal voltage changes from High to Low, and the alarm output terminal conducts to GND. Furthermore, since a 1.3kΩ resistance is connected in series between the control IC and the alarm output terminal, an optocoupler that is connected between the ALM terminal and the V_{CC} terminal can be directly driven.

□ Alarm signal output function

If the abnormal mode is detect, the IGBT is slowly turn-off. The alarm signal is output from the phase in which abnormal mode is detected. During the protection period, the IGBT is not turned on even if the control input signal is in ON-state.

- After the elapse of t_{ALM}, if the alarm factor has been resolved, and the control input signal is OFF-state, the protection operation is reset and normal operation is resumed.
- Even if the alarm factor is resolved within the alarm signal output period (t_{ALM}), the protection operation continues during the alarm signal output period (t_{ALM}), and the IGBT will not turn on. If the control input signal is OFF-state after the alarm signal output period (t_{ALM}) has elapsed, the protection operation is reset and normal operation is resumed.
- On the upper arm side, the IGBT of the phase that detected the abnormal mode shutdown softly and stops operation.
- On the lower arm side, when each phase of the inverter section goes into protection, all IGBTs of the lower arm except the brake IGBT shutdown softly and stop operation. The brake IGBT can be operated. Also, in the event of an abnormality in the brake section, all IGBTs in the lower arm and brake IGBT will shutdown softly and stop operation.

* P629 and P639 package have protection functions on both of the upper arm and the lower arm devices, but the upper arm devices do not have an alarm signal output function. The lower arm devices have both the protective functions and alarm signal output function.

□ Alarm factor identification function

As the alarm signal output period (t_{ALM}) varies in correspondence to the failure mode, the failure mode can be identified by measuring the alarm signal pulse width.

Alarm factor	Alarm signal output period (t_{ALM})
Over current protection(OC) Short-circuit protection(SC)	2ms(typ)
Control power supply under voltage protection(UV)	4ms(typ)
Chip temperature overheat protection(T_{jOH})	8ms(typ)

However, the pulse width of the alarm signal output through an optocoupler varies depending on the delay time of the optocoupler and the influence of peripheral circuits. It is necessary to take these influences into account in your design.

2.5 Over current protection function (OC)

The collector current of IGBTs is detected by the current sense IGBT built into the IGBT chip. If the collector current reaches the over current protection level (I_{OC}) and continues for more than the over current protection delay time (t_{dOC}), it is determined as being in the OC status and the IGBT is turned off to prevent destruction due to over current.

When the OC status is detected, the protection function is activated and an alarm signal is output. The OC status alarm signal output period (t_{ALM}) is approximately 2ms.

- Protection operation is reset after 2ms (t_{ALM}) and normal operation is resumed if the current level is lower than the I_{OC} level and the control input signal is OFF.
- Even if the alarm factor is resolved within 2ms (t_{ALM}), the protection operation continues until the period of 2ms (t_{ALM}) elapses. During this period, the IGBT will not be turned on.

2.6 Short circuit protection function (SC)

The SC protection function prevents the IPM from being damaged by the peak current during load short circuit and arm short circuit. If the IGBT collector current exceeds the protection level (I_{SC}) and continues for more than the short circuit protection delay time (t_{sc}), it is determined as being in the SC status and the IGBT is turned off softly to prevent destruction due to short circuit.

When the SC status is detected, the protection function is activated and an alarm signal is output. The SC status alarm signal output period (t_{ALM}) is approximately 2ms.

- Protection operation is reset after 2ms (t_{ALM}) and normal operation is resumed if the current level is lower than the I_{SC} level and the input signal is OFF.
- Even if the alarm factor is resolved within 2ms (t_{ALM}), the protection operation continues until the period of 2ms (t_{ALM}) elapses. During this period, the IGBT will not be turned on.

2.7 Control power supply under voltage protection function (UV)

The UV protection function prevents malfunction of the control IC caused by voltage drop of the control power supply voltage (V_{CC}), and protects the IGBT from thermal destruction caused by increase of $V_{CE(sat)}$ loss. When V_{CC} is continuously below the under voltage protection level (V_{UV}) for about 20μs, it is determined as being in the UV status and the IGBTs are turned off softly to prevent malfunction and thermal destruction due to control power supply voltage drop.

When the UV status is detected, the protection function is activated and an alarm signal is output. The UV status alarm signal output period (t_{ALM}) is approximately 4ms.

- As hysteresis V_H is provided, protection operation is reset after 4ms (t_{ALM}) and normal operation is resumed if V_{CC} is higher than (V_{UV} + V_H) and the input signal is OFF.
- Even if the alarm factor is resolved within 4ms (t_{ALM}), the protection operation continues until the period of 4ms (t_{ALM}) elapses. During this period, the IGBT will not be turned on.
  Furthermore, an alarm signal to determine the UV status is provided at the time of startup and shutdown of the control power supply V_{CC}.

2.8 IGBT chips over heating protection function (T_{jOH})

Over heating protection function detects the IGBT chip surface temperature by the built-in temperature sensor on each IGBT chip. If the IGBT chip temperature continuously exceeds the over heating protection level (T_{jOH}) for about 1ms, the IGBT is judged to be in an over heating state and the IGBT is turned off softly to prevent thermal destruction.

When the T_{jOH} state is detected, the protection function is activated and alarm signal is output. The T_{jOH} state alarm signal output period (t_{ALM}) is approximately 8ms.

- As hysteresis T_{jH} is provided, protection operation is reset after 8ms (t_{ALM}) and normal operation is resumed if T_{vj} is below (T_{jOH} - T_{jH}) and the input signal is OFF.
- Even if the alarm factor is resolved within 8ms (t_{ALM}), the protection operation continues until the end of the period of 8ms (t_{ALM}) elapses. During this period, the IGBT will not be turned on.

The case temperature over heating protection function (T_{cOH}), which is built in the previous IPM series, is not built in this X series. The IGBT chip is protected by the T_{jOH} protection function.

2.9 Temperature warning output function (T_{jW})

Temperature warning output function directly detects the IGBT chip surface temperature by the built-in temperature sensor on the Y phase IGBT chip. If the IGBT chip temperature continuously exceeds the warning temperature level (T_{jW}) for about 1ms, the IGBT is judged to be in an over heating state and a temperature warning signal is output from the warning signal output terminal. With this function, it is possible to determine in advance that the IPM is overheated before it is stopped by over heating protection. During this state, the over heating protection function and alarm signal output function will not operate. (Even if the temperature warning output signal is generated, the protection is not activated and the IPM continues to operate.) The temperature warning signal output period (t_{WNG}) continues until the factor is released.

- As hysteresis T_{jWH} is provided, warning output signal is canceled if T_{vj} is below (T_{jW} - T_{jWH}).
  This function is available only in the Fuji 7th generation X series IGBT-IPM in the following package.
  P626 , P636(6in1) , P638 , P630(6in1) , P631(6in1)

3. Truth table

The truth table when a failure occurs are shown in Table 3-3.

Table 3-3 Truth table

	Alarm factor	IGBT					Alarm output signal				Warning output signal
		U-phase	V-phase	W-phase	X,Y,Z-phase	B-phase	ALM -U	ALM -V	ALM -W	ALM -Low side	WNG
U-phase	OC	OFF	*	*	*	*	Low	High	High	High	*
	SC	OFF	*	*	*	*	Low	High	High	High	*
	UV	OFF	*	*	*	*	Low	High	High	High	*
	T_{jOH}	OFF	*	*	*	*	Low	High	High	High	*
V-phase	OC	*	OFF	*	*	*	High	Low	High	High	*
	SC	*	OFF	*	*	*	High	Low	High	High	*
	UV	*	OFF	*	*	*	High	Low	High	High	*
	T_{jOH}	*	OFF	*	*	*	High	Low	High	High	*
W-phase	OC	*	*	OFF	*	*	High	High	Low	High	*
	SC	*	*	OFF	*	*	High	High	Low	High	*
	UV	*	*	OFF	*	*	High	High	Low	High	*
	T_{jOH}	*	*	OFF	*	*	High	High	Low	High	*
X,Y,Z-phase	OC	*	*	*	OFF	*	High	High	High	Low	*
	SC	*	*	*	OFF	*	High	High	High	Low	*
	UV	*	*	*	OFF	*	High	High	High	Low	*
	T_{jOH}	*	*	*	OFF	*	High	High	High	Low	*
Y-phase	T_{jW}	*	*	*	*	*	High	High	High	High	Low
B-phase	OC	*	*	*	OFF	OFF	High	High	High	Low	*
	SC	*	*	*	OFF	OFF	High	High	High	Low	*
	UV	*	*	*	OFF	OFF	High	High	High	Low	*
	T_{jOH}	*	*	*	OFF	OFF	High	High	High	Low	*

* Dependent on the input signal.
※P639 and P629 do not have ALM output for the upper arm (U, V, W phase).

The brake phase can operate normally even if the lower arm X, Y, and Z phases are under protection. When the protection operation is activated in the brake phase, all the lower arm phases including the brake phase go into protection state.

4. Block diagram of IPM

IPM block diagrams are shown in Figure 3-3 to 3-5.
Figure 3-3 shows an example of P629 (6in1) without alarm functions on the upper arms.
Figure 3-4 shows an example of P630 (6in1) and Figure 3-5 shows an example of P630 (7in1).

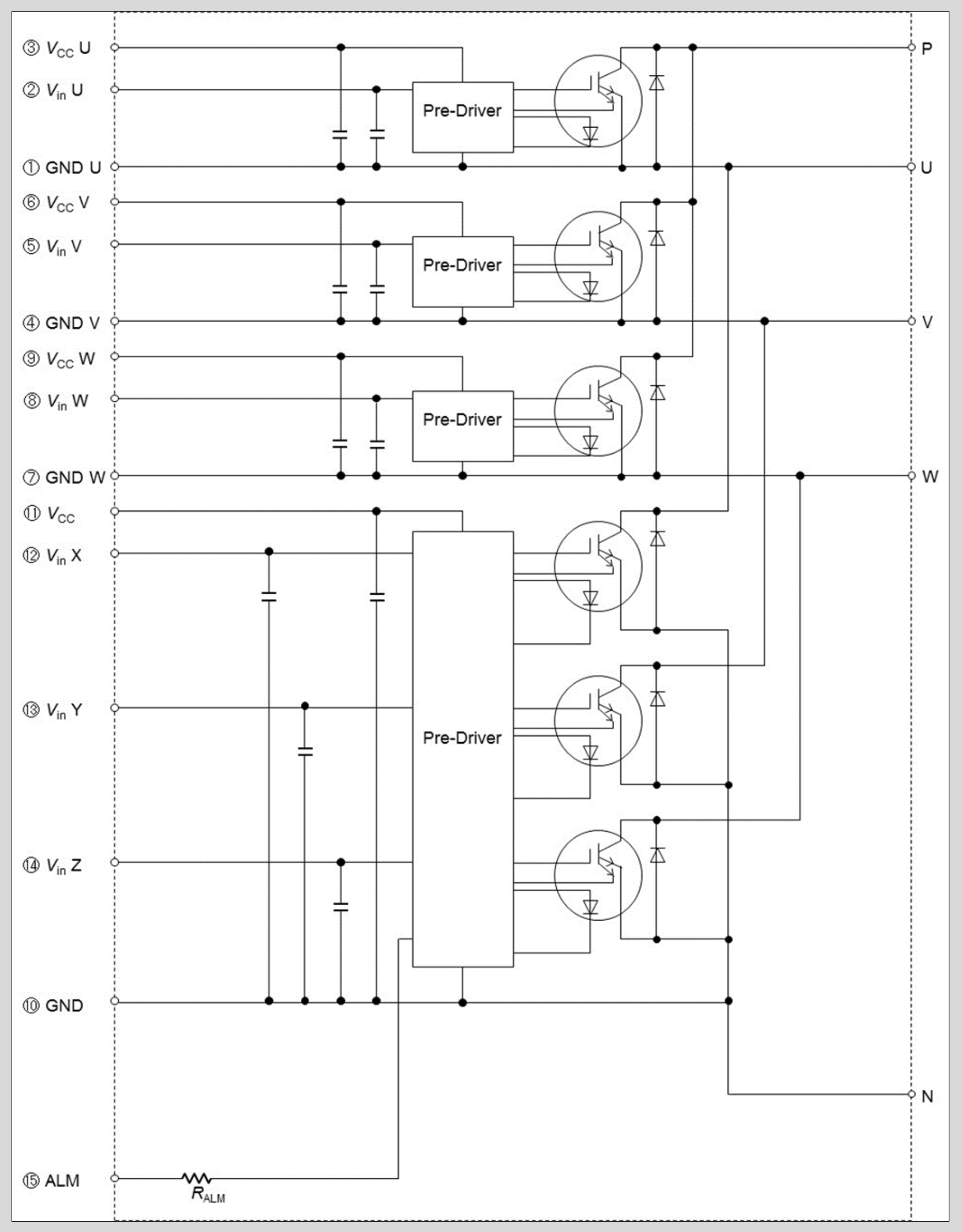


Fig. 3-3 IPM block diagram (example: P629)

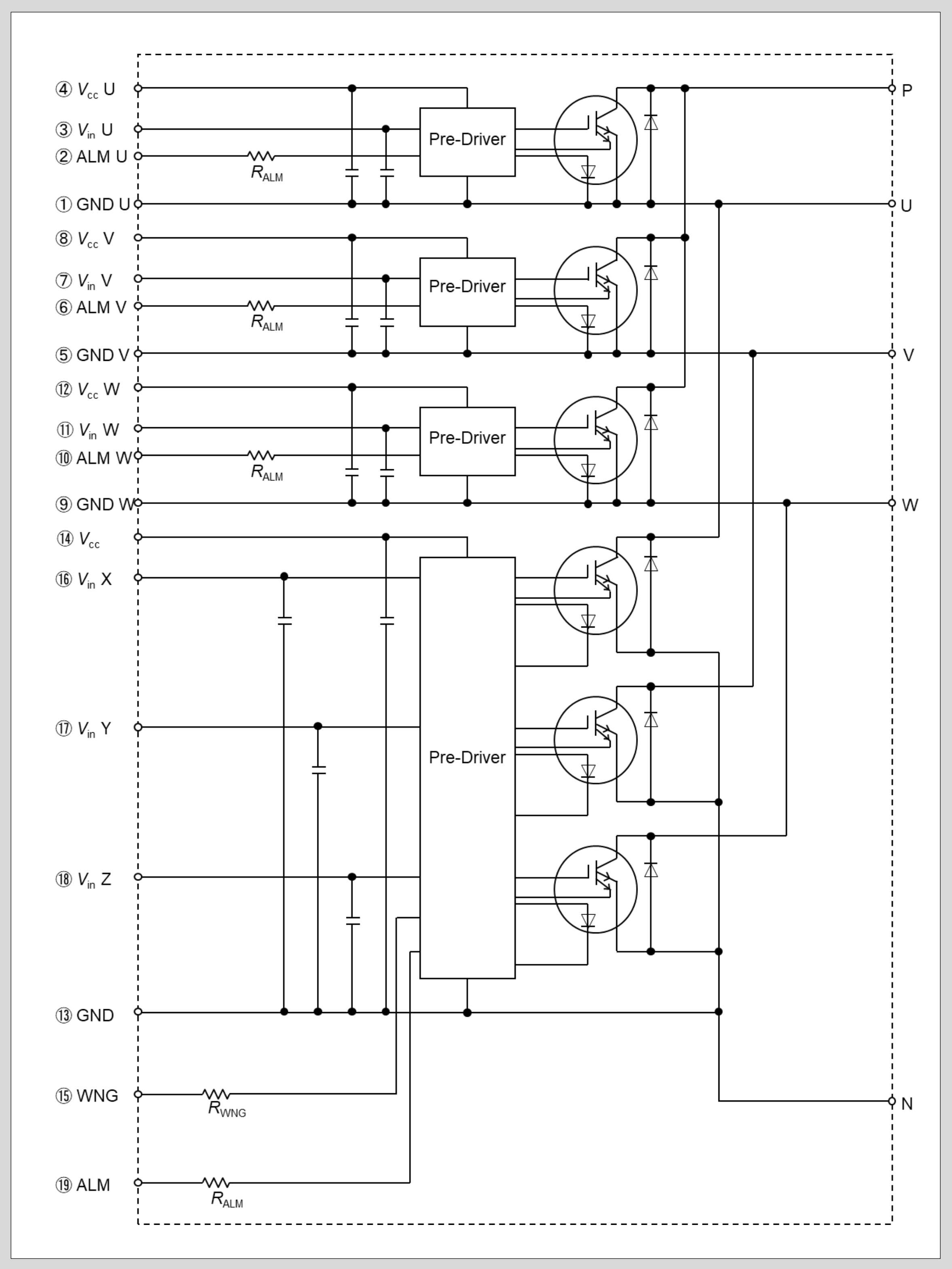


Fig. 3-4 IPM block diagram (example: P630 (6in1))

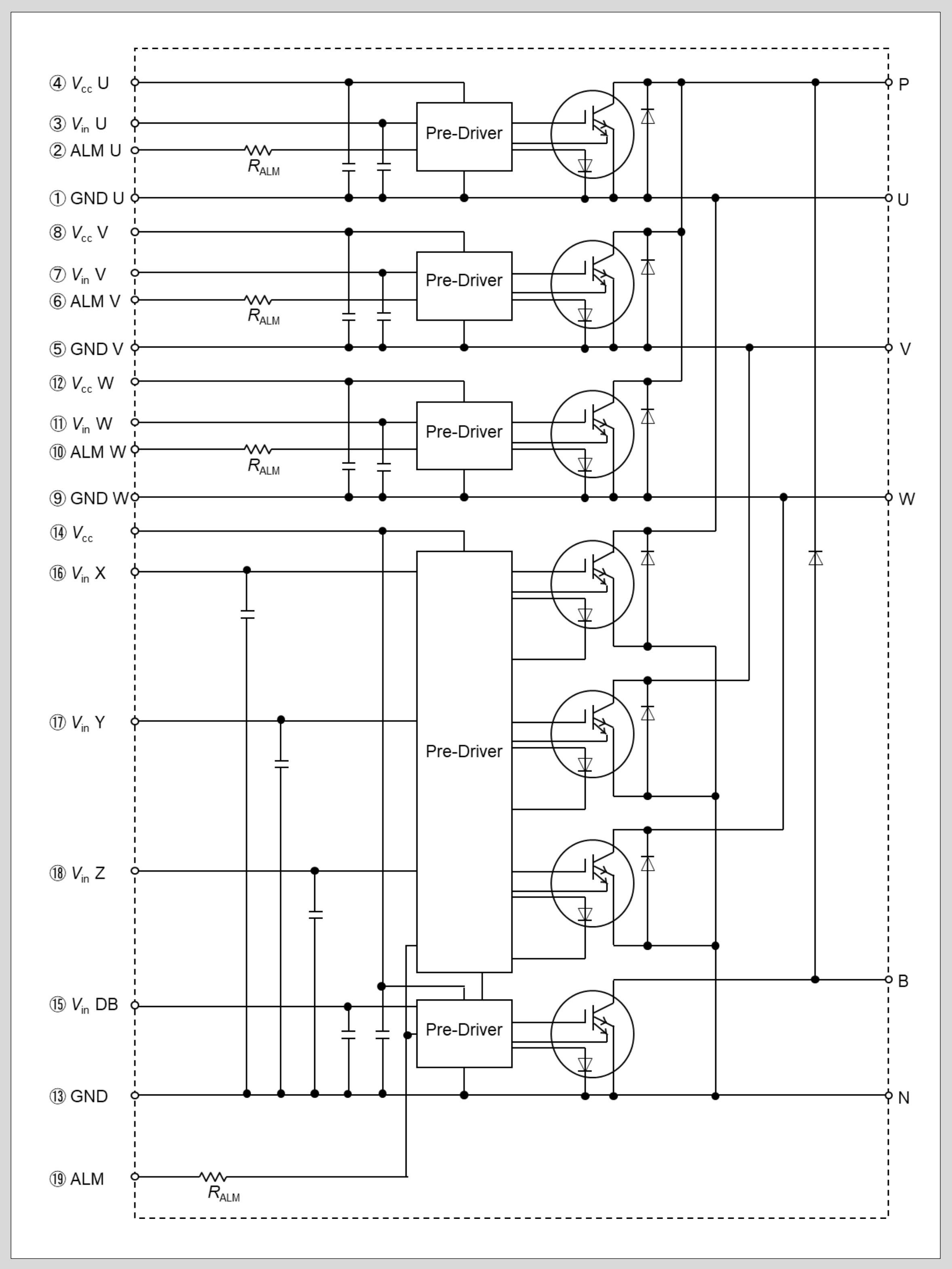


Fig. 3-5 IPM block diagram (example: P630 (7in1))

5. Timing chart

5.1 Control power supply under voltage protection (UV)

5.1.1 Operation when V_{CC} is turned on and V_{in} is High (OFF). (operation (1)~(4))

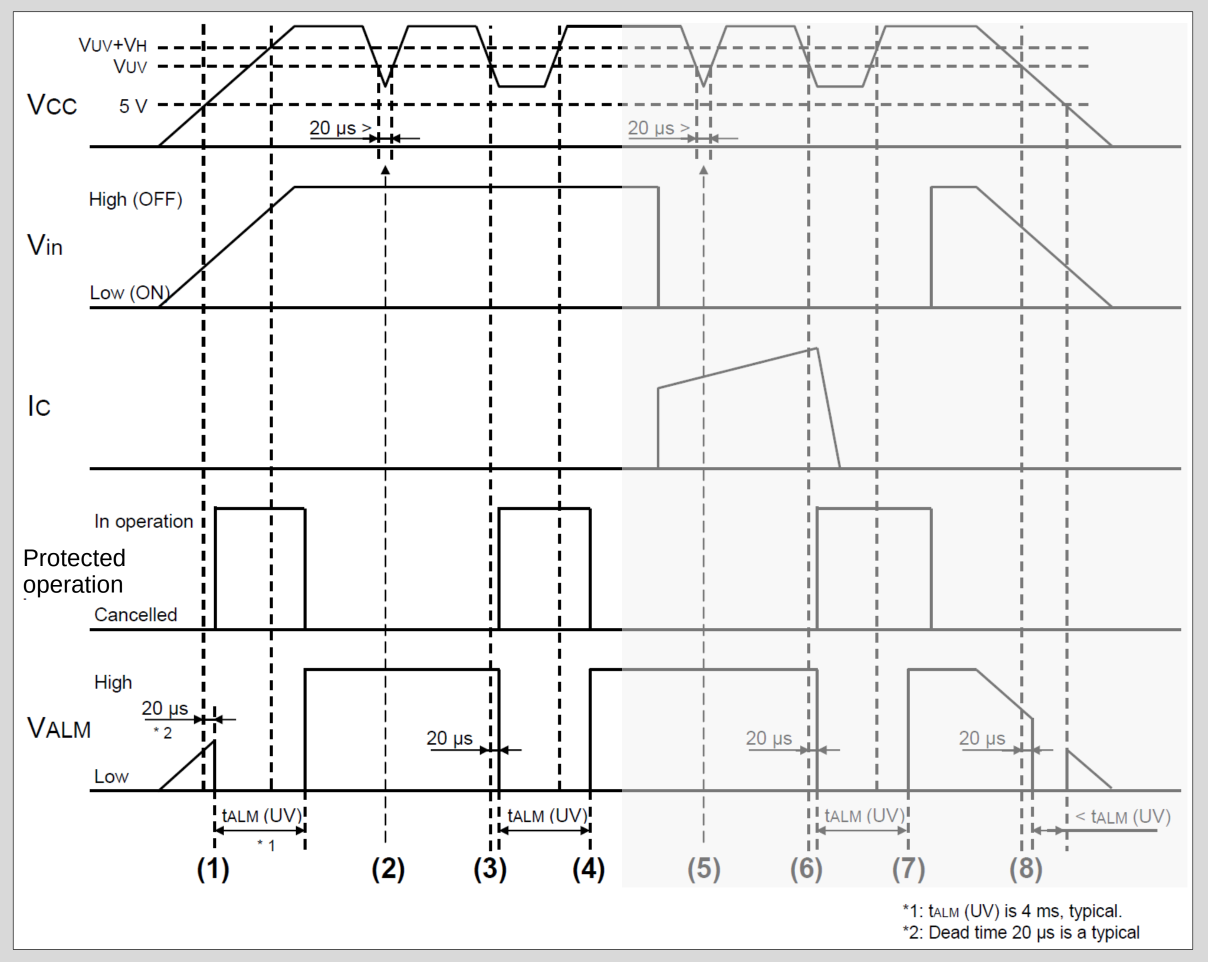


Fig. 3-6 UV protection operation ((1)~(4))

- During V_{CC} startup, an alarm signal is output when V_{CC} exceeds 5V and becomes lower than V_{UV}. (1)
  The protection is not activated regardless of whether the V_{in} signal is in ON/OFF state if the period during which V_{CC} is lower than V_{UV} is shorter than 20μs. (2)
- The alarm signal is output about 20μs after V_{CC} drops below V_{UV}.
  While V_{in} is OFF, the IGBT is kept in the OFF-state. (3)
- UV protection operation continues during the $t_{ALM(UV)}$ period if V_{CC} returns to $V_{UV}+V_H$ before $t_{ALM(UV)}$ elapses. (3)~(4)
  When V_{in} is OFF, normal operation is resumed after $t_{ALM(UV)}$ has elapsed. (4)
- Even if the protection operating duration is sufficiently longer than $t_{ALM(UV)}$, the alarm signal is output only once.

V_{CC}	: Supply voltage of pre-driver	V_{UV}	: Under voltage protection level
V_H	: Under voltage protection hysteresis	V_{in}	: Input signal voltage
V_{ALM}	: Alarm signal voltage	$t_{ALM(UV)}$	: Alarm signal hold time

5.1.2 Operation when V_{in} is Low (ON) and V_{CC} is shut off. (operation (5)~(8))
Protection operation recovery (4) ~ V_{CC} power off period.

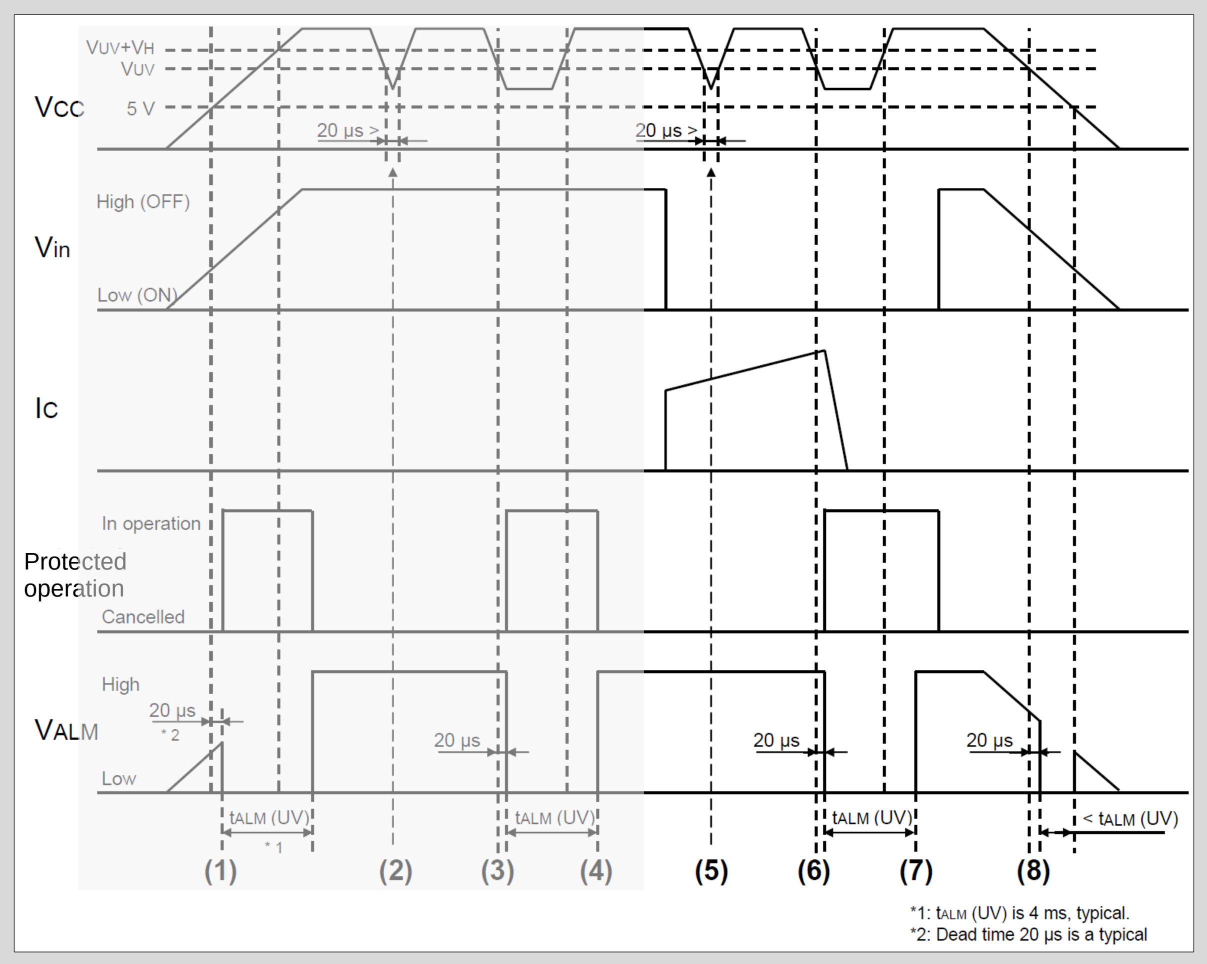


Fig. 3-7 UV protection operation ((5)~(8))

- The protection is not activated regardless of whether the V_{in} signal is ON/OFF-state if the period during which V_{CC} is lower than V_{UV} is shorter than 20μs. (5)
- The alarm signal is output about 20μs after V_{CC} drops below V_{UV}.
  While V_{in} is in ON, the alarm signal is output about 20μs after V_{CC} drops below V_{UV} , and the IGBT is turned off softly ※1. (6)
- In case V_{in} remains ON, the alarm signal is output for the $t_{ALM(UV)}$ period, but the protection function continues operating after that.
  When V_{in} is in OFF, normal operation is resumed. (7)
- During V_{CC} shut off, the alarm signal is output when V_{CC} drops below V_{UV}.(8)
- Even if the protection operating duration is sufficiently longer than $t_{ALM(UV)}$, the alarm signal is output only once.

※1 Soft turn off : This means a slower than normal turn-off.

V_{CC}	: Supply voltage of pre-driver	V_{UV}	: Under voltage protection level
V_H	: Under voltage protection hysteresis	V_{in}	: Input signal voltage
V_{ALM}	: Alarm signal voltage	$t_{ALM(UV)}$	: Alarm signal hold time

5.2 Control power supply under voltage protection (UV) during startup and shutdown of power supply

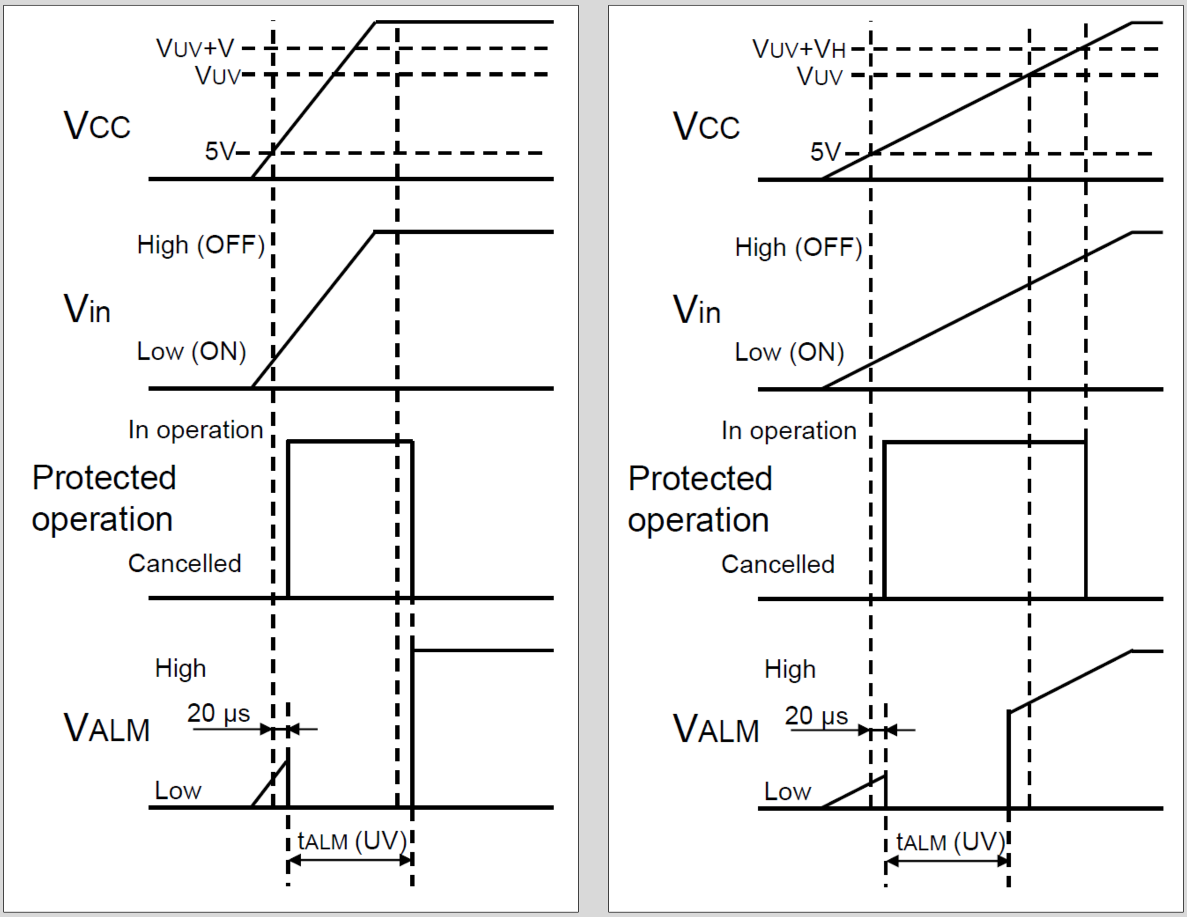
The X-IPM has control power supply under voltage protection (UV) function. Because of this function, an alarm signal is output during the startup and shutdown of the power supply.

5.2.1 During start up

When V_{CC} exceeds 5V, an alarm signal is output after the elapse of 20μs in both Case 1 (when the inclination of V_{CC} is fast) and Case 2 (when the inclination of V_{CC} is slow).

In Case 1, V_{CC} exceeds V_{UV} + V_H and V_{in} becomes OFF-state before $t_{ALM(UV)}$ elapses, thus the protection operation is stopped after the elapse of $t_{ALM(UV)}$.

In Case 2, the protection operation continues even after the elapse of $t_{ALM(UV)}$ because V_{CC} is still below V_{UV} + V_H. The protection operation is stopped when V_{CC} exceeds V_{UV} + V_H and V_{in} is in OFF-state.



(a) Case 1 When the inclination of V_{CC} is fast. (b) Case 2 When the inclination of V_{CC} is slow.

Fig.3-8 V_{CC} start up operation

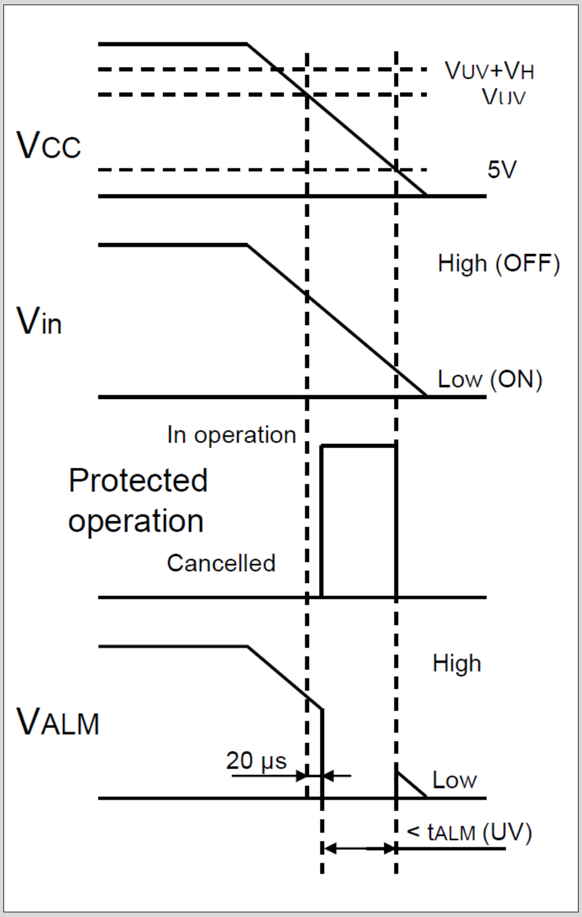
V_{CC} : Supply voltage of pre-driver
V_H : Under voltage protection hysteresis
V_{ALM} : Alarm signal voltage
V_{UV} : Under voltage protection level
V_{in} : Input signal voltage
$t_{ALM(UV)}$: Alarm signal hold time

5.2.2 During Shutdown

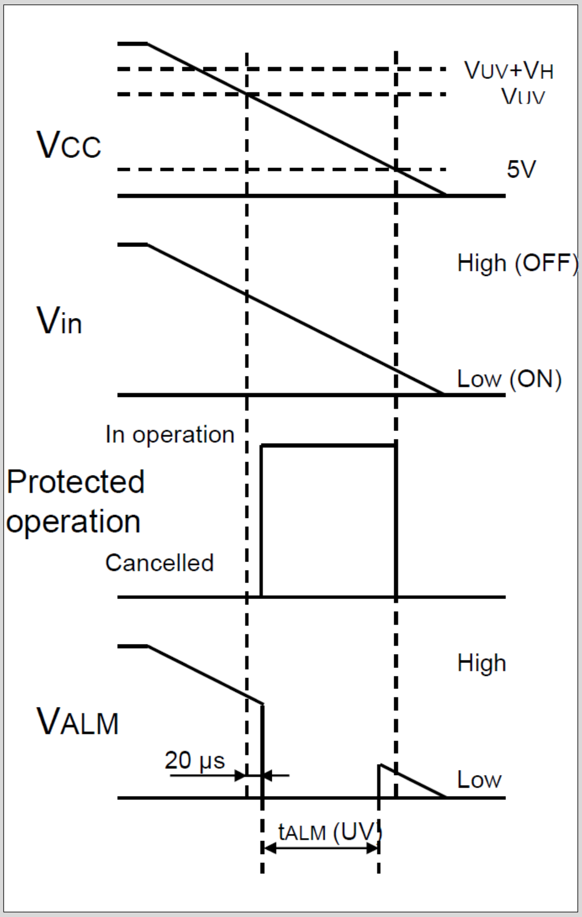
When V_{CC} falls below V_{UV}, an alarm signal is output after the elapse of 20μs in both Case 3 (when the inclination of V_{CC} is fast) and Case 4 (when the inclination of V_{CC} is slow).

In Case 3, the alarm signal output is stopped before the elapse of $t_{ALM(UV)}$ because V_{CC} falls below 5V and the control IC does not operate normally.

In Case 4, the protection operation continues after the elapse of $t_{ALM(UV)}$ because V_{CC} still exceeds 5V. However, when V_{CC} falls below 5V, the control IC does not operate normally and V_{ALM} changes to V_{CC} equivalent.



(a) Case 3 When the inclination of V_{CC} is fast.



(b) Case 4 When the inclination of V_{CC} is slow.

Fig.3-9 V_{CC} shutdown operation

V_{CC}	: Supply voltage of pre-driver	V_{UV}	: Under voltage protection level
V_H	: Under voltage protection hysteresis	V_{in}	: Input signal voltage
V_{ALM}	: Alarm signal voltage	$t_{ALM(UV)}$	: Alarm signal hold time

5.3 Multiple alarm signal output from lower arm during control power supply under voltage protection (UV)

Some X series IPM have multiple independent control ICs on the lower arm. These alarm signal outputs are a common output on the lower arm. Therefore, there are some cases when several alarm are output because of the variation in the under voltage protection level of the control ICs. If d*v*/d*t* of V_{UV} is less than 0.5V/ms in the vicinity of V_{CC}, there is possibility of alarm output such as shown in Figure 3-10. (This is not an abnormal phenomenon.)

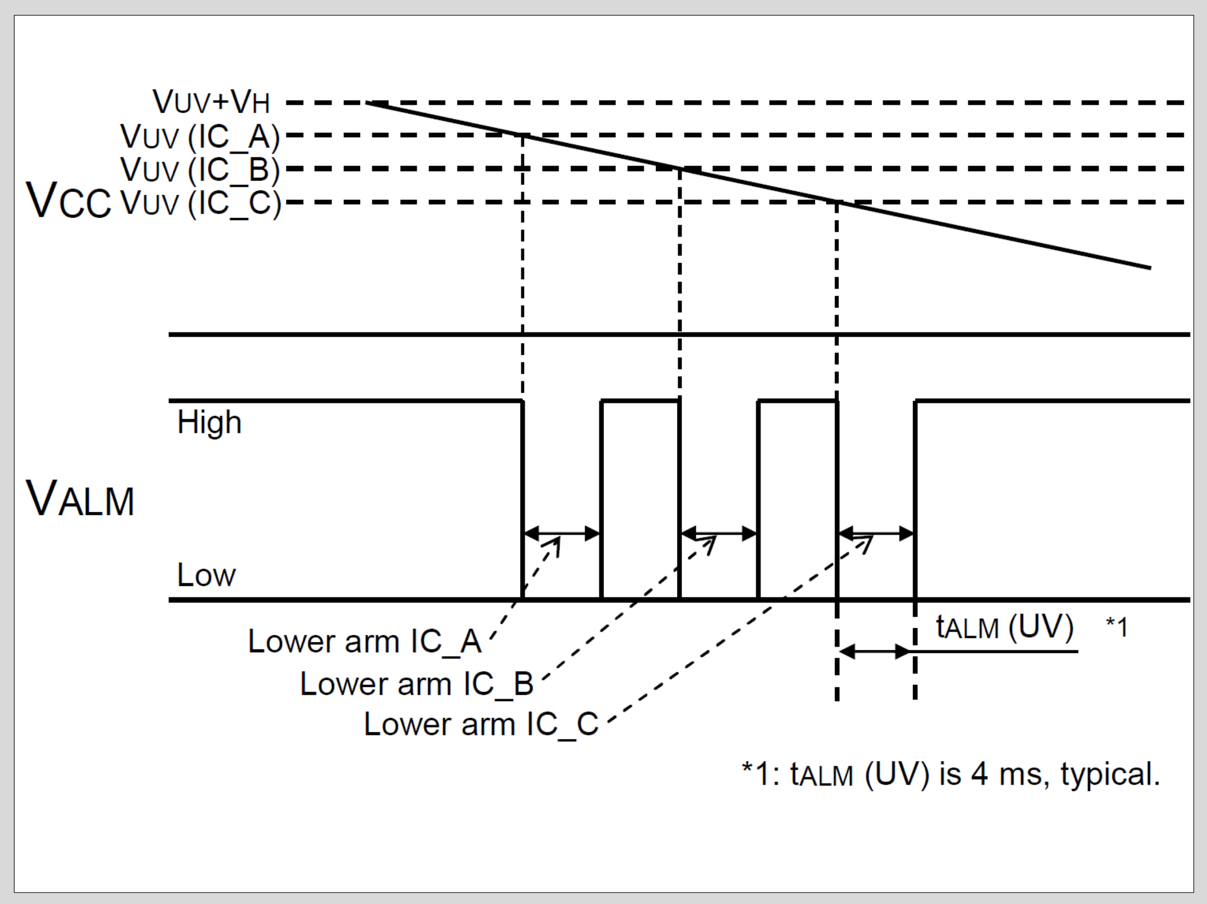


Fig.3-10 UV alarm output of lower arm

V_{CC} : Supply voltage of pre-driver
V_{ALM} : Alarm signal voltage
V_{UV} : Under voltage protection level
$t_{ALM(UV)}$: Alarm signal hold time

5.4 Over current protection (OC) operation

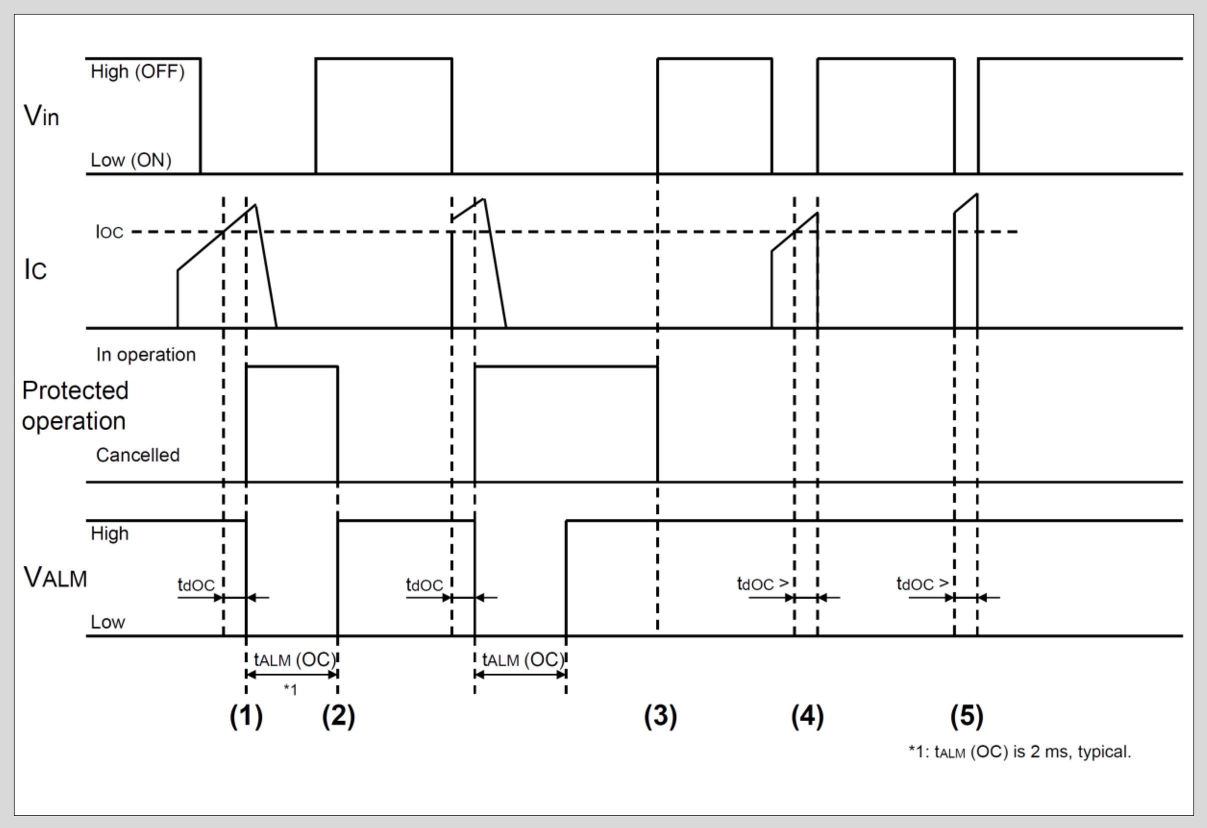


Fig.3-11 OC protection operation

- When I_C exceeds the over current protection level I_{OC}, an alarm signal is output after the elapse of t_{dOC}, and the IGBT is turned off softly ※1. (1)
- The protection operation continues during the period of $t_{ALM(OC)}$ even if V_{in} is in OFF-state, and resumes to normal operation after the elapse of $t_{ALM(OC)}$ if V_{in} becomes OFF-state. (2)
- The protection operation continues if V_{in} is in ON-state after the elapse of $t_{ALM(OC)}$, and resumes to normal operation if the V_{in} becomes OFF-state. (3)
- If V_{in} is in OFF-state before the elapse of t_{dOC} after I_C exceeds I_{OC}, the protection operation is not activated and the IGBT is turned off normally ※2. (4)
- Even if I_C exceeds I_{OC} when V_{in} is in ON-state, if V_{in} becomes OFF-state before the elapse of t_{dOC}, the protection operation is not activated and the IGBT is turned-off normally. (5)
- Even if the protection operating duration is sufficiently longer than $t_{ALM(OC)}$, the alarm signal is output only once.

※1 Soft turn off: This means a slower than normal turn-off.
※2 Normal turn off: This means a normal turn-off operation.

V_{in}	: Input signal voltage	V_{ALM}	: Alarm signal voltage
I_C	: Collector current	I_{OC}	: Over current protection level
$t_{ALM(OC)}$	: Alarm signal hold time	t_{dOC}	: Over current protection delay time

5.5 Short circuit protection (SC) operation

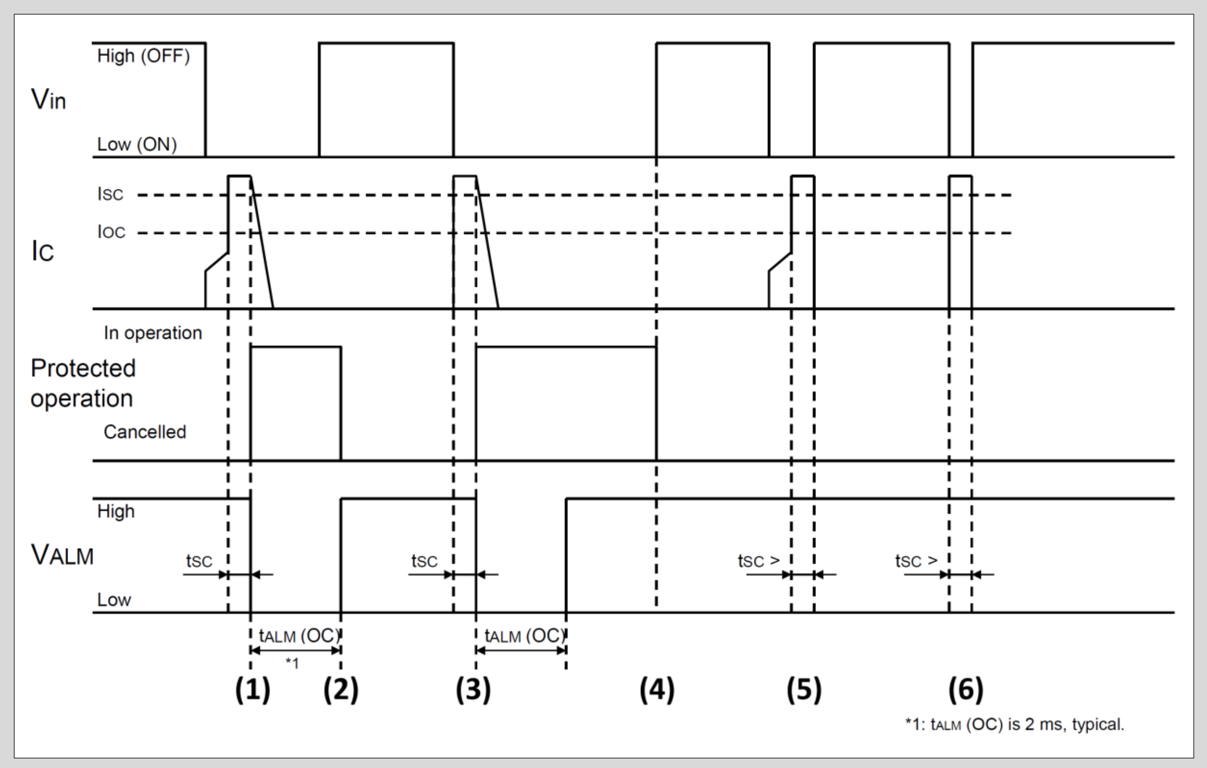


Fig.3-12 SC protection operation

- If a load short circuit occurs after I_C is flowing and I_C exceeds I_{SC}, the peak current of I_C is suppressed momentarily. After the elapse of t_{SC}, an alarm signal is output and the IGBT is turned off softly ※1. (1)
- The SC protection operation is stopped if V_{in} is in OFF-state after the elapse of $t_{ALM(OC)}$. (2)
- If a load short-circuit occurs as soon as I_C began to flow and I_C exceeds I_{SC}, the peak current is suppressed momentarily. After the elapse of t_{SC}, the alarm signal is output and the IGBT is turned off softly. (3)
- The SC protection operation continues even after the elapse of $t_{ALM(OC)}$ if V_{in} is in ON-state. The SC protection operation is stopped when V_{in} becomes OFF-state. Even if the protection operating duration is sufficiently longer than $t_{ALM(OC)}$, the alarm signal is output only once. (4)
- If a load short-circuit occurs after I_C began to flow, the peak current of I_C is suppressed momentarily as soon as the I_C exceeds I_{SC}. After that, if V_{in} becomes OFF-state before the elapse of t_{SC}, the SC protection operation is not activated and the IGBT is turned off normally ※2. (5)
- If a load short-circuit occurs as soon as I_C began to flow and I_C exceeds I_{SC}, I_C peak is suppressed momentarily. If V_{in} becomes OFF-state before the elapse of t_{SC}, the SC protection operation is not activated and the IGBT is turned off normally. (6)

※1 Soft turn off: This means a slower than normal turn-off.
※2 Normal turn off: This means a normal turn-off operation.

V_{in} : Input Signal Voltage
I_C : Collector current
I_{SC} : SC trip level
$t_{ALM(OC)}$: Alarm signal hold time
t_{SC} : Short circuit protection delay time

5.6 IGBT chips over heating protection (T_{jOH}) operation
: When the ON/OFF state of V_{in} affects the protection operation

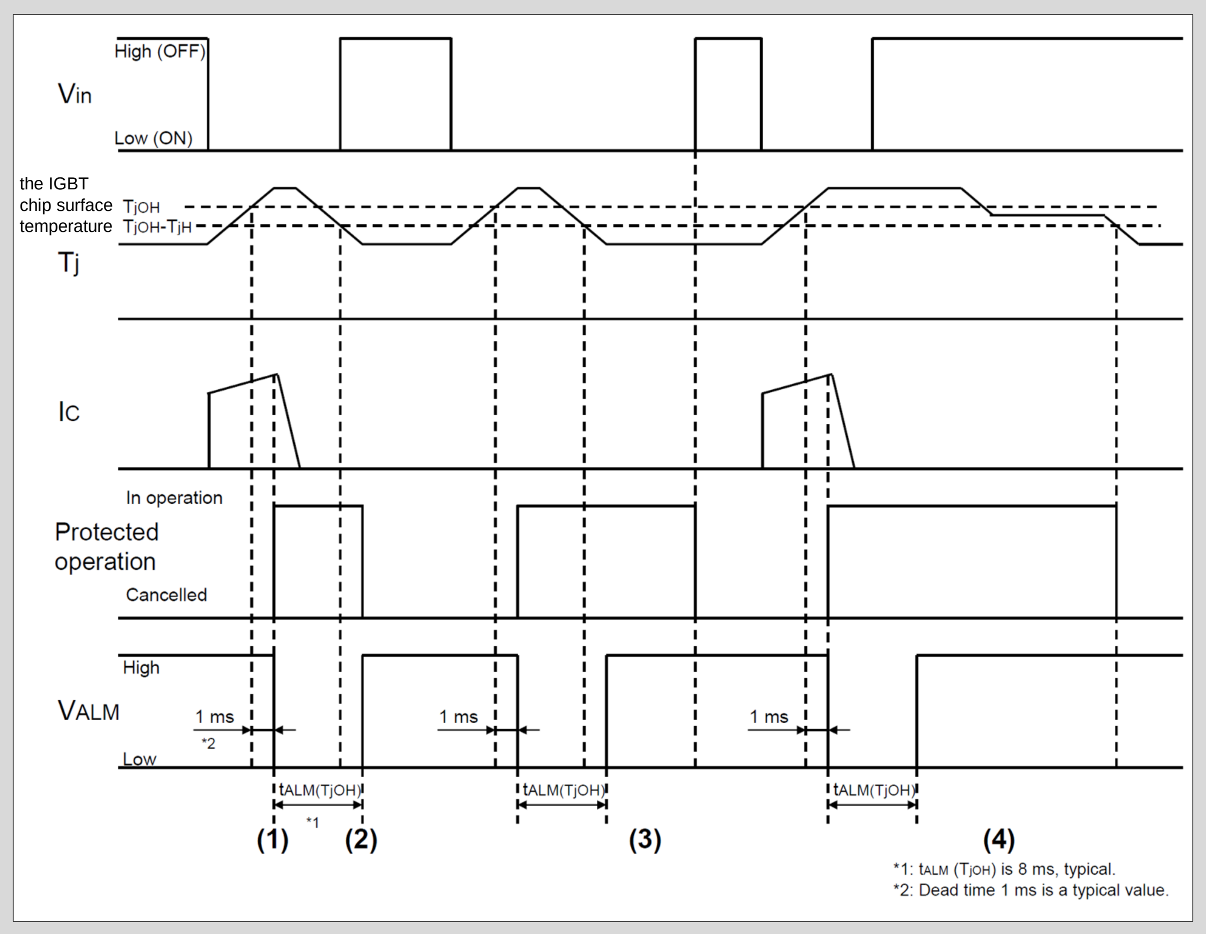


Fig.3-13 T_{jOH} protection operation (1)

- If the IGBT chip surface temperature T_{vj} is higher than T_{jOH} continuously for a period exceeding 1ms, an alarm signal is output and the IGBT is turned off softly※1. (1)
- The protection operation continues during the period of $t_{ALM(TjOH)}$ even if T_{vj} drops below T_{jOH} - T_{jH} before the elapse of $t_{ALM(TjOH)}$. Normal operation resumes if V_{in} is in OFF-state after the elapse of $t_{ALM(TjOH)}$. (2)
- The protection operation continues if V_{in} is in ON-state, even if T_{vj} drops below T_{jOH} - T_{jH} after the elapse of $t_{ALM(TjOH)}$. (3)
- The protection operation continues after the elapse of $t_{ALM(TjOH)}$ even when V_{in} is in OFF-state if T_{vj} exceeds T_{jOH} - T_{jH}. Even if the protection operating duration is sufficiently longer than $t_{ALM(TjOH)}$, the alarm signal is output only once. (4)

※1 Soft turn off: This means a slower than normal turn-off.

V_{in} : Input signal voltage
V_{ALM} : Alarm signal voltage
$t_{ALM(TjOH)}$: Alarm signal hold time
T_{jOH} : IGBT chips over heating protection temperature level
T_{jH} : Over heating protection hysteresis

5.7 IGBT chips over heating protection (T_{jOH}) operation
: When the ON/OFF state of V_{in} does not affect the protection operation

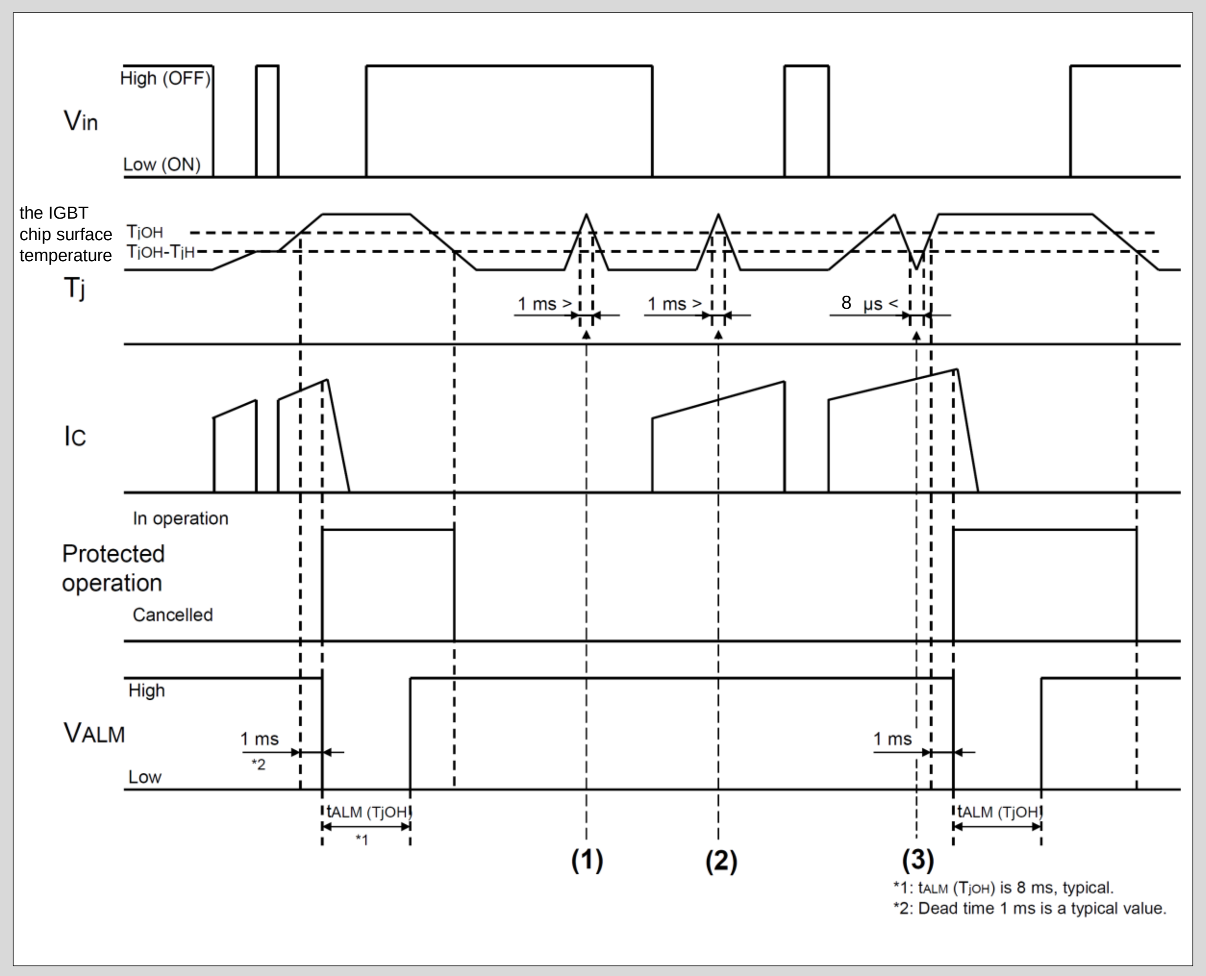


Fig.3-14 T_{jOH} protection operation (2)

- The protection operation is not activated if the IGBT chip surface temperature T_{vj} exceeds and drops below T_{jOH} within 1ms, regardless of whether V_{in} is in ON or OFF. (1),(2)
- If T_{vj} drops below T_{jOH} - T_{jH} for longer than 8μs after T_{vj} exceeds T_{jOH}, the T_{jOH} detection timer of which duration is approximately 1ms is reset. (3)

V_{in} : Input signal voltage
V_{ALM} : Alarm signal voltage
I_C : Collector current
$t_{ALM(TjOH)}$: Alarm signal hold time
T_{jOH} : IGBT chips over heating protection temperature level
T_{jH} : Over heating protection hysteresis

5.7 Control power supply under voltage protection (UV) operation during IGBT chips over heating protection (T_{jOH}) operation (1)~(3)

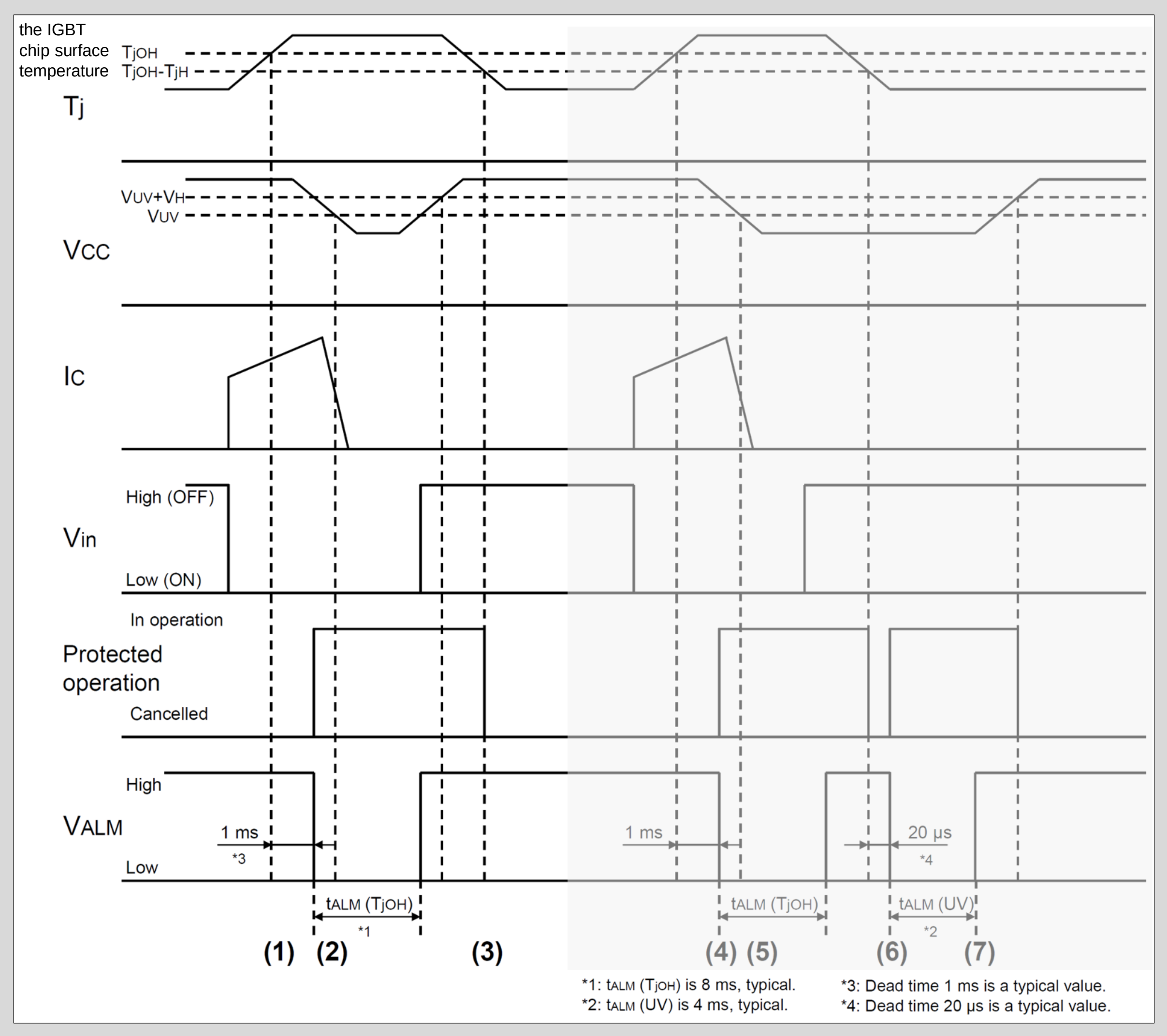


Fig.3-15 T_{jOH} combined protection operation (1)~(3)

- When the IGBT chip surface temperature T_{vj} exceeds T_{jOH} for 1ms continuously, an alarm signal is output and the IGBT is turned off softly ※1. (1)
- If V_{CC} drops below V_{UV} before the elapse of $t_{ALM(TjOH)}$, the alarm signal output by UV protection is cancelled because the protection operation of $t_{ALM(TjOH)}$ continues. (2)
- The protection operation is reset after the elapse of $t_{ALM(TjOH)}$ if V_{in} is in OFF-state and T_{vj} drops below T_{jOH} -T_{jH}. (3)

※1 Soft turn off: This means a slower than normal turn-off.

V_{CC}	: Supply voltage of pre-driver	V_{UV}	: Under voltage protection level
V_{in}	: Input signal voltage	V_{ALM}	: Alarm signal voltage
I_C	: Collector current	$t_{ALM(UV)}$	: Alarm signal hold time
$t_{ALM(TjOH)}$	: Alarm signal hold time		
T_{jOH}	: IGBT chips over heating protection temperature level		
T_{jH}	: Over heating protection hysteresis		

5.8 Control power supply under voltage protection (UV) operation after IGBT chips over heating protection (T_{jOH}) operation ends (4)~(7)

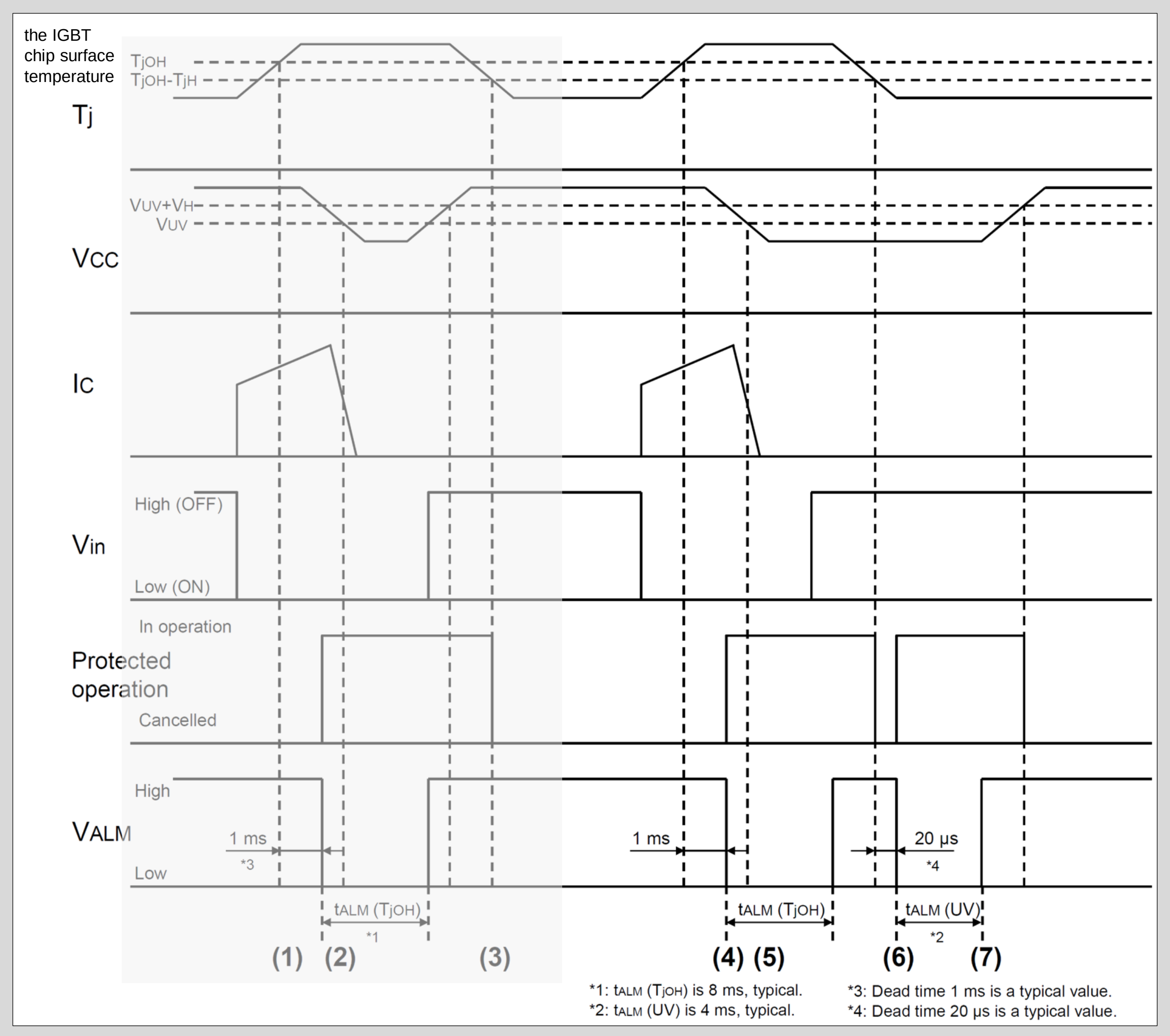


Fig.3-16 T_{jOH} combined protection operation (4)~(7)

- When the IGBT chip surface temperature T_{vj} exceeds T_{jOH} for 1ms continuously, an alarm signal is output and the IGBT is turned off softly ※1. (4)
- Similar to (2), the alarm signal output by UV protection is cancelled while the protection operation of $t_{ALM(TjOH)}$ continues. (5)
- The protection operation is reset after the elapse of $t_{ALM(TjOH)}$ if V_{in} is in OFF-state and T_{vj} drops below T_{jOH} - T_{jH}. After this, if V_{CC} drops below V_{UV} continuously for 20μs, UV protection is activated and the alarm signal is output. (6)
- The protection operation is stopped after the elapse of $t_{ALM(UV)}$ if V_{in} is in OFF-state and V_{CC} exceeds V_{UV} + V_H. (7)

※1 Soft turn off: This means a slower than normal turn-off.

$t_{ALM(TjOH)}$: Alarm signal hold time

$t_{ALM(UV)}$: Alarm signal hold time

T_{jOH} : IGBT chips over heating protection temperature level

T_{jH} : Over heating protection hysteresis

5.9 IGBT chip temperature warning output operation

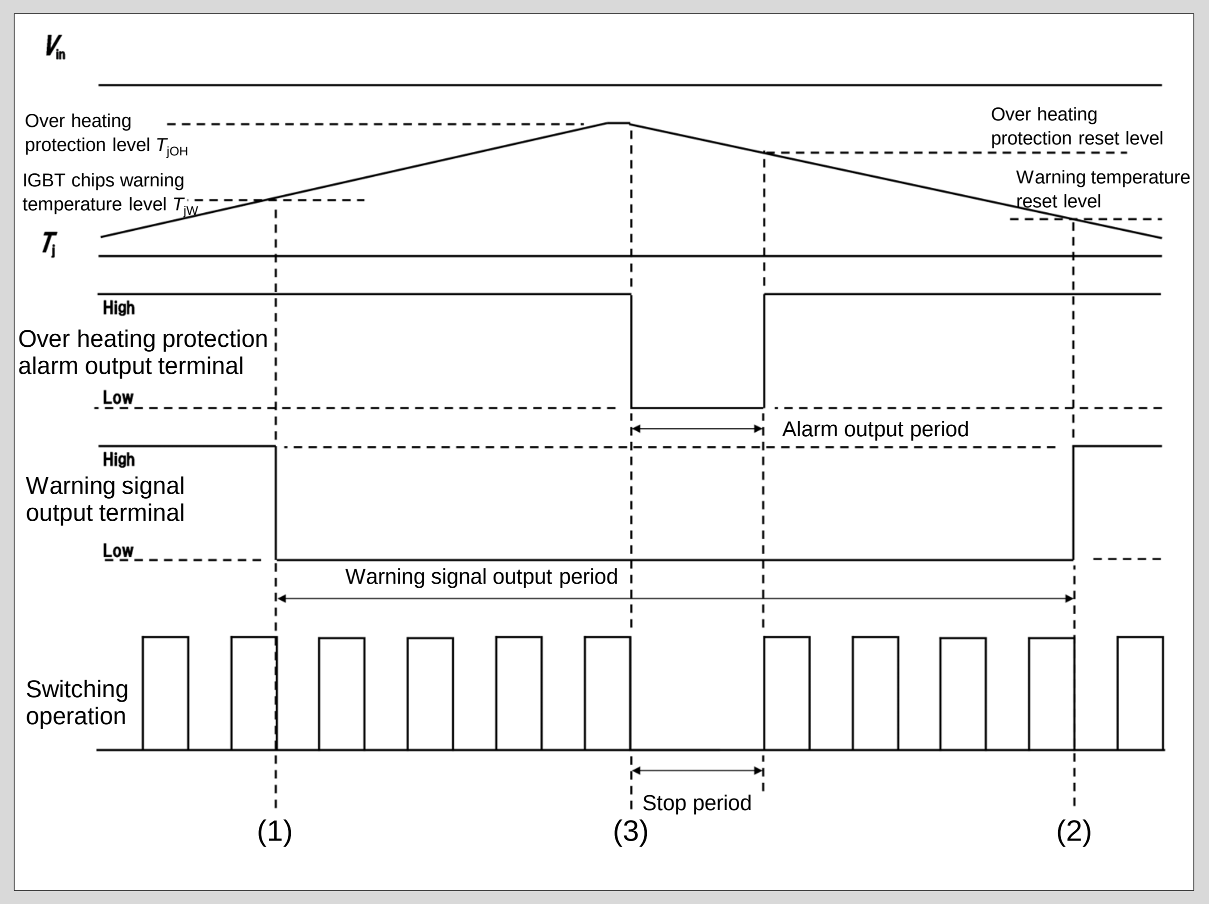


Fig.3-17 Chip temperature warning operation

- A chip temperature warning signal is output before the switching operation is stopped by IGBT chips over heating protection. During this time, the switching operation continues.
- When the IGBT chip surface temperature T_{vj} reaches the IGBT chips warning temperature level T_{jW}, the T_{vj} warning signal output terminal voltage changes from V_{CC} to 0V. During this time, the switching operation continues. (1)
- When T_{vj} falls below T_{jW}, the T_{vj} warning signal output terminal voltage returns to V_{CC}. (2)
- Next, if T_{vj} exceeds T_{jOH} in the state of (1), an alarm signal is output and the switching operation is stopped. (3)

V_{CC} : Supply voltage of pre-driver
T_{jOH} : IGBT chips over heating protection temperature level

Chapter 4 Typical application circuits

This chapter describes the typical application circuits of the X series IPM.

1. Typical application circuits

Figure 4-1 shows the typical application circuits of P629 and P639 (6in1, only lower arm has alarm signal output function.)

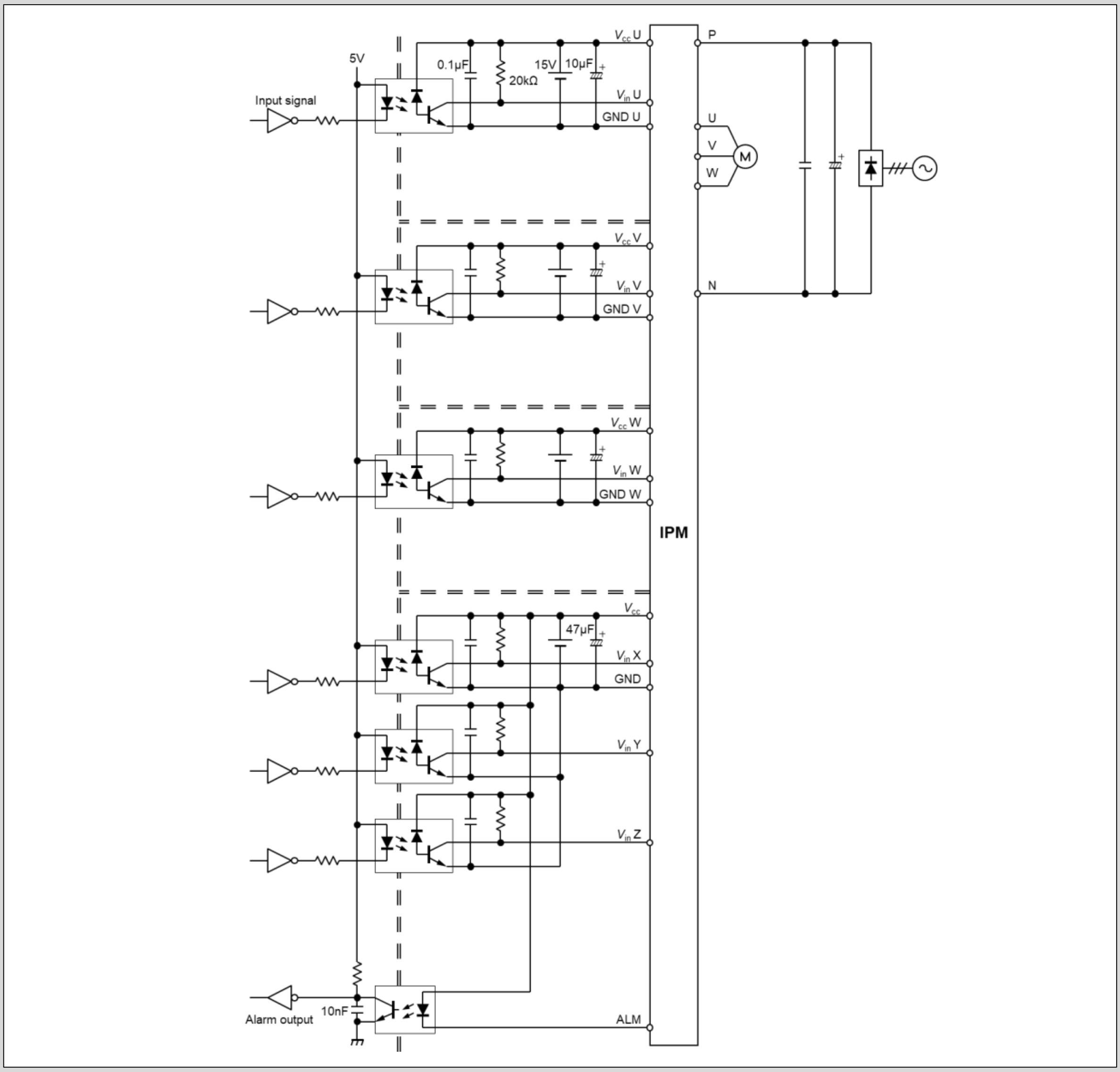
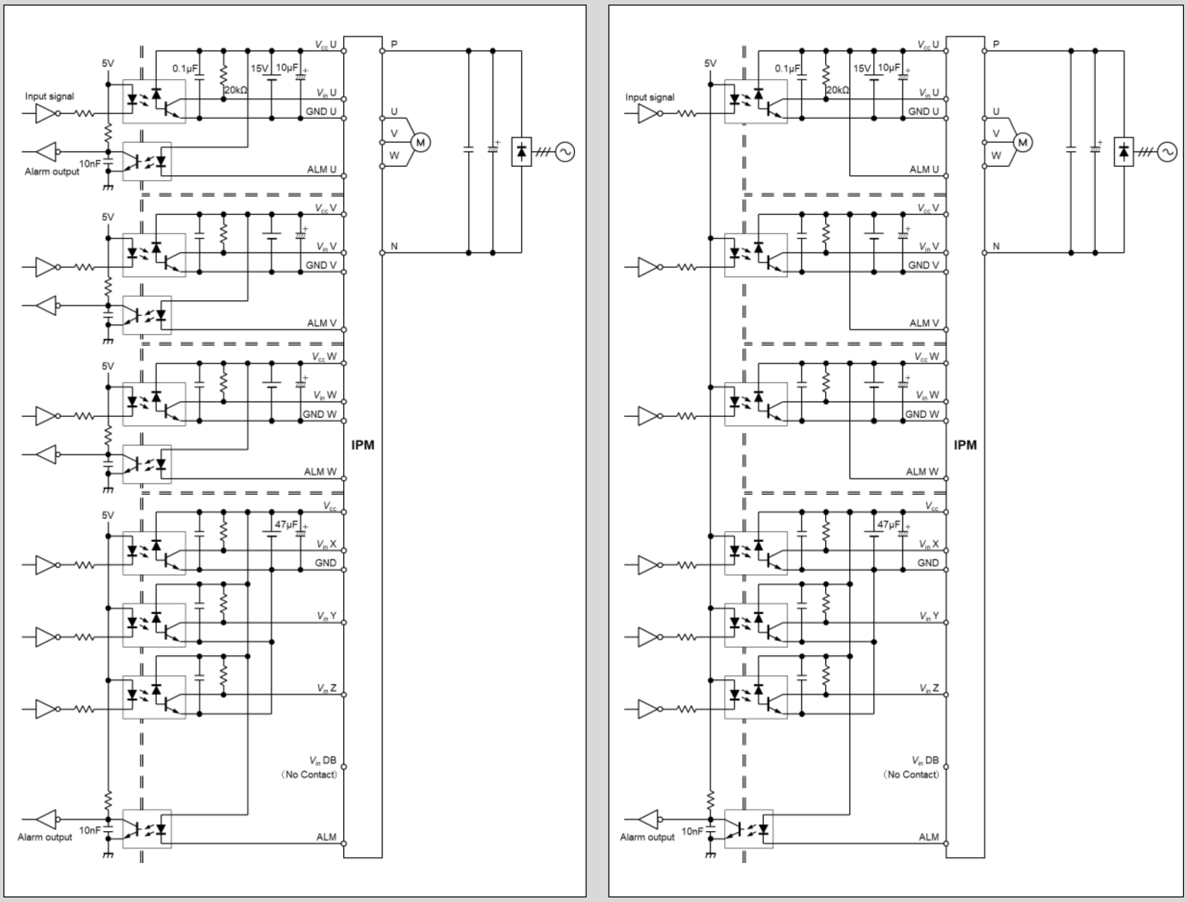


Fig.4-1 Typical application circuits of P629 and P639

Figure 4-2 shows the typical application circuits of P626 and P636 (6in1)

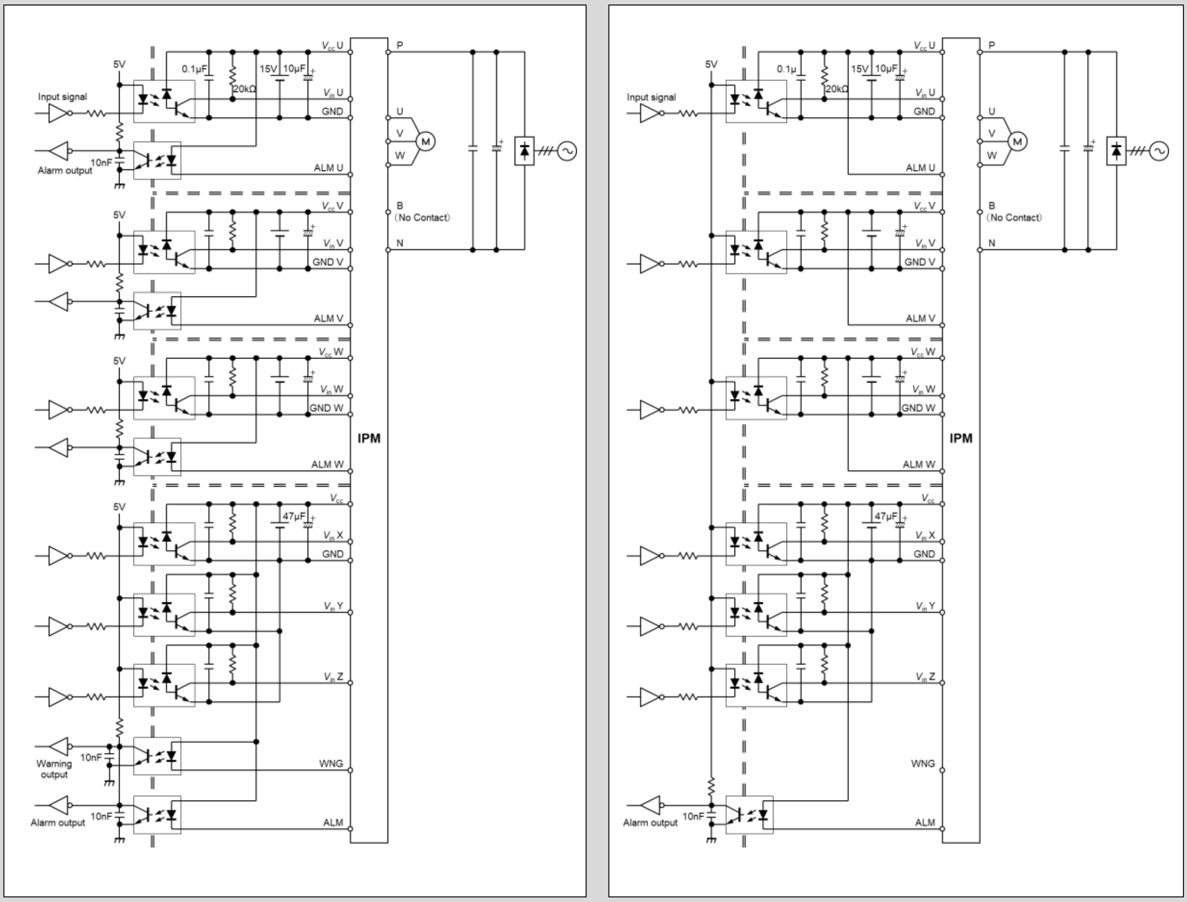


(a) When using the upper arms alarm

(b) When not using the upper arms alarm

Fig.4-2 Typical application circuits of P626 and P638

Figure 4-3 shows the typical application circuits of P626, P630, P631, P636 and P638 (6in1, with temperature warning function type).

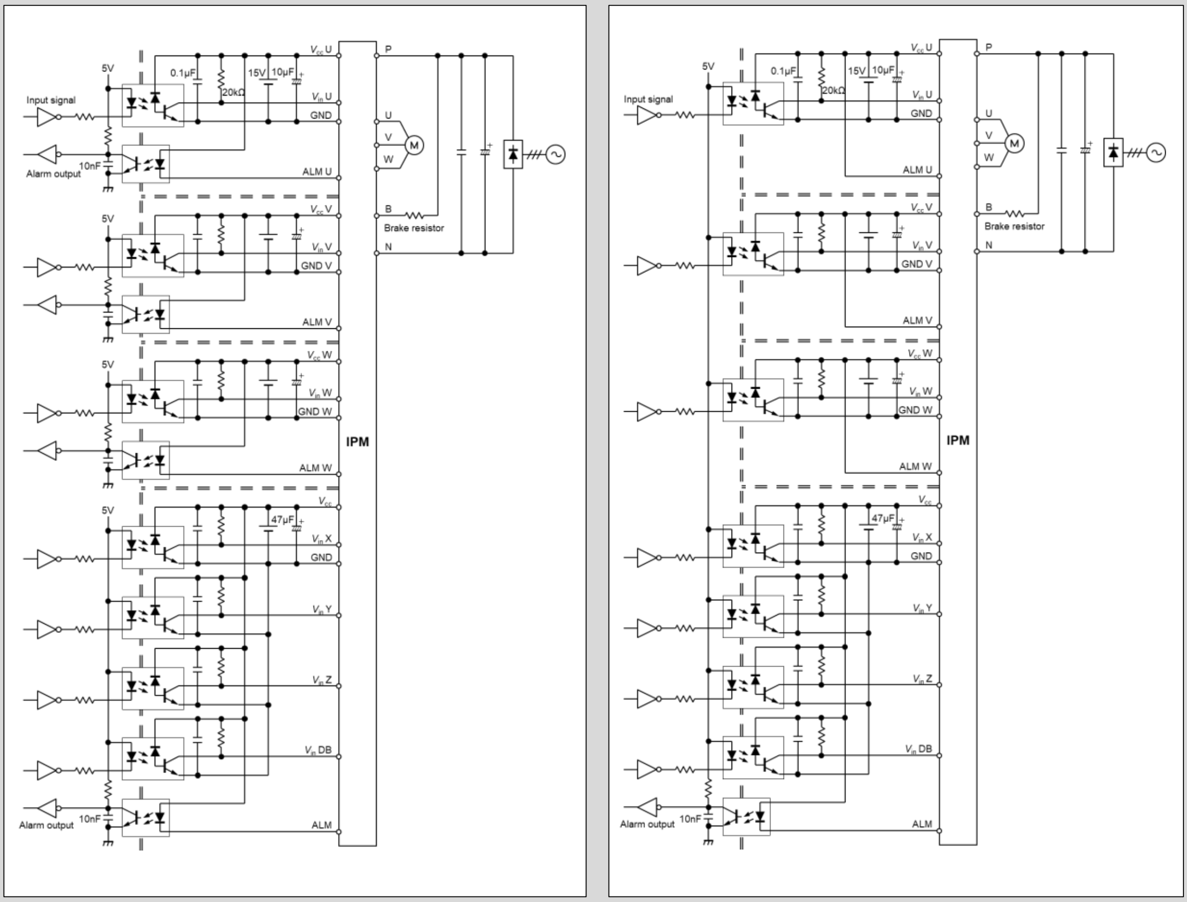


(a) When using the upper arms alarm (b) When not using the upper arms alarm

Fig.4-3 Typical application circuits of P626, P630, P631, P636 and P638 (6in1, with temperature warning function)

- If the temperature warning function is not used, open the WNG terminal.
  If the WNG terminal is connected to the V_{CC} terminal, the consumption current I_{CC} increases when the temperature of the IPM reaches the temperature warning level.

Figure 4-4 shows the typical application circuits of P630, P631, P636 and P644 (7in1, with built-in brake).



(a) When using the upper arms alarm (b) When not using the upper arms alarm

Fig.4-4 Typical application circuits of P630, P631, P636 and P644 (7in1)

2. Important remarks

2.1 Control power supply units

A total of four isolated power supply units; three for the upper arm and one for the lower arm are required as shown in the application circuit examples. Mount an aluminum electrolytic capacitor (upper arm: approx.50V/10µF, lower arm: approx.50V/47µF）as close as possible to the control power terminal V_{CC} of the IPM. This capacitor is not for smoothing the control power supply, but for compensating the wiring impedance up to IPM. It is predicted that the use of only a single power supply such as a bootstrap causes voltage fluctuations. Thus, careful consideration and verification are required.

When using a commercially available power supply unit, do not use the output GND terminal of the power supply unit. If the GND of the output side is connected to the + or − terminals, it may cause a malfunction because each power supply unit is connected to the power ground of input side. Furthermore, reduce the stray capacitance (floating capacitance) between the power supply unit and the GND as much as possible.

In addition, use a power supply unit with sufficient Icc supply capacity and reduce output voltage fluctuations.

2.2 Structural insulation between four power supply units (input portion connector and PCB)

The four power supply units and the main power source have to be insulated from each other. Be sure to secure a sufficient insulation distance because high dv/dt is applied to this insulation part during IGBT switching. (2 mm or longer is recommended)

2.3 GND connection

Do not connect the control terminal GND U and the main terminal U, control terminal GND V and main terminal V, control terminal GND W and main terminal W, control terminal GND and main terminal N (N1 and N2 in the case of P631) to external circuits. In that case, it may cause a malfunction.

2.4 External capacitors for control power supply

Capacitors of 10µF (47µF) and 0.1µF connected to each power supply unit shown in typical application circuits are not used for smoothing the output voltage of the power supply units, but for compensating the wiring impedance from the power supply unit up to the IPM. Additional smoothing capacitors are required. Furthermore, these external capacitors should be connected as close as possible to the IPM control terminals or optocoupler terminals because transient fluctuation occurs in the wiring impedance between these capacitors and the control circuits.

An electrolytic capacitor which has low impedance and good frequency characteristics is recommended. In addition, it is recommended to connect a film capacitor with good frequency characteristics in parallel.

2.5 Alarm circuit

The X-IPM has a built-in 1.3kΩ alarm output resistor, so that an optocoupler can be connected to the terminal directly without an external resistor. The wiring distance between the optocoupler and the IPM should be as short as possible. Also, the pattern layout should be designed to minimize the floating capacitance between the primary side and the secondary side of the optocoupler.

Since a dv/dt may cause the secondary side potential of the optocoupler to fluctuate, it is recommended to connect a capacitor of about 10nF to the output terminal on the secondary side of the optocoupler to stabilize the potential as shown in Figure 4-4.

Furthermore, regarding IPMs with an upper arm alarm output function, connect the alarm output terminal to V_{CC} as shown in Figure 4-4 (b) in order to stabilize the potential if the upper arm alarm output function is not used.

2.6 Warning circuit (specific models only)

Since the X-IPM has a built-in 1.3kΩ warning output resistor, the optocoupler can be directly connected without an external resistor. When connecting the optocoupler, make not only the wiring between the optocoupler and the IPM as short as possible, but also the pattern layout that reduces the stray capacitance between the primary and secondary sides of the optocoupler.

Since a dv/dt may cause the secondary side potential of the optocoupler to fluctuate, it is recommended to connect a capacitor of about 10nF to the output terminal on the secondary side of the optocoupler in order to stabilize the potential.

Also, when the temperature warning function is operating, the consumption current by V_{CC}/R_{WNG} increases, so please consider the design of the power supply. If the temperature warning function is not used, it is recommended to keep the WNG terminal open. If the warning terminal is pulled up to V_{CC}, the consumption current increases when the temperature warning function operates. Thus, design the power supply properly. In addition, do not pull down the warning terminal to GND.

2.7 Pull-up of signal input terminal

Connect the control signal input terminals to V_{CC} through a 20kΩ pull-up resistor. Furthermore, unused input terminals also have to be pulled up to V_{CC} through the 20kΩ resistor. If these terminals are not pulled up to V_{CC}, UV protection is activated and IPM cannot be operate.

2.8 Connection when there is an unused phase

If there are cases when a 6in1 (without brake part) is used in only single phase or a 7in1(with brake part) is used without brake part, supply control voltage to these unused phase and connect the input/alarm terminals to V_{CC} to stabilize the potential of these terminals. The warning signal output terminal is excluded.（refer to 4.2.6)

2.9 Handling of unconnected terminals (no contact terminals)

Unconnected terminals (no contact terminals) are not connected inside of the IPM. These terminals are insulated from other terminals. There is no need of special treatment such as potential stabilization.

Also, guide pins are not connected inside of the IPM.

2.10 Snubber

Directly connect a snubber circuit to the P/N terminals as close as possible. For P631 package which has two P/N terminals, it is effective to connect snubber circuits to both P1-N1 and P2-N2 terminals to reduce surge voltage. Do not connect snubber circuits across the two terminals such as P1-N2 and P2-N1 as it may cause a malfunction.

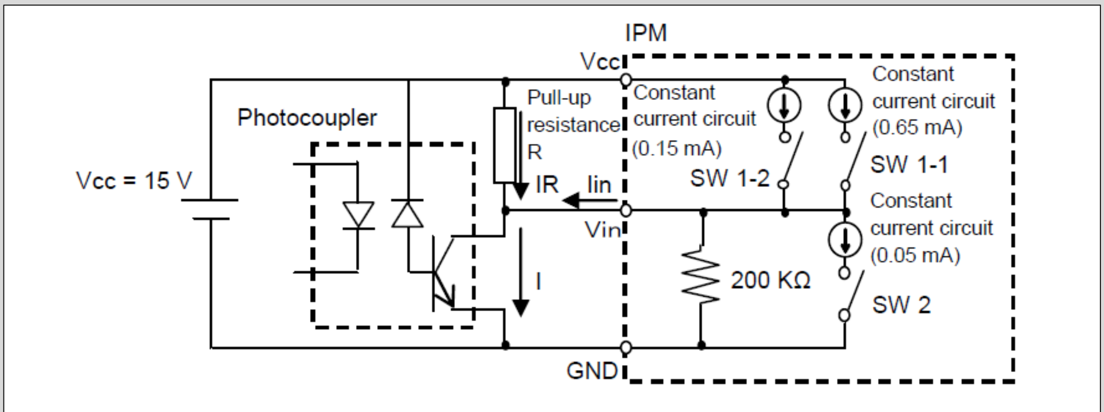
2.11 Grounding capacitor

Connect grounding capacitors between each AC input line and its ground to prevent noise from flowing in the system.

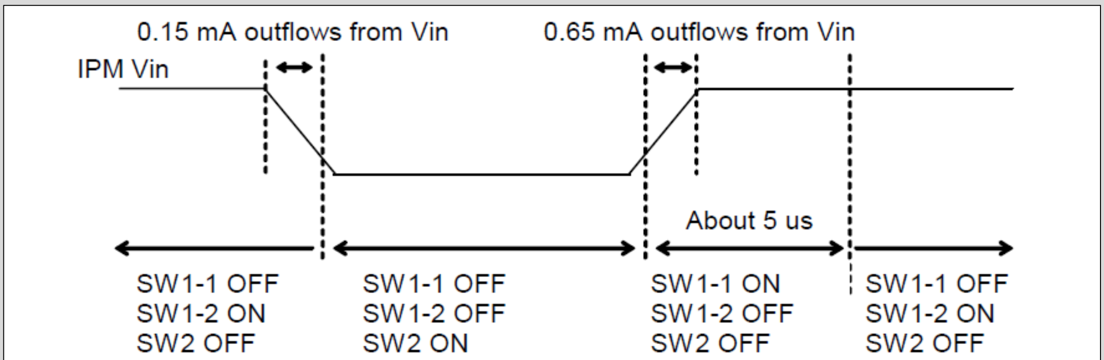
.

2.12 Input circuit of IPM

There are constant current circuits in the input circuit of IPMs as shown in Figure 4-5(a).
The constant current of I_{in} = 0.15 mA or I_{in} = 0.65 mA flows at that timing shown in Figure 4-5(b).
The current of the secondary side of optocoupler is the sum of the constant current I_{in} and the current through a pull-up resistor I_R. Therefore, it is necessary to determine the current of the primary side of optocoupler I_F so that sufficient current can flow in the secondary side of optocoupler. If I_F is insufficient, the secondary side may a malfunction.



(a) IPM input circuit



* The operating time of the constant current circuit (0.65 mA) is the period until V_{in} reaches V_{CC}.
It is about 5 μs at maximum.

(b) constant current operation timing

Fig.4-5 IPM input circuit and constant current operation timing

3. Optocoupler peripheral circuits

3.1 Optocoupler for control input

3.1.1 Optocoupler rating

Use an optocoupler that satisfies the following characteristics.

- CMH = CML > 15kV/μs or 10kV/μs
- tpHL = tpLH < 0.8μs
- tpLH – tpHL = -0.4～0.9μs
- CTR > 15%

Example:
HCPL-4504 by Broadcom
TLP759 (IGM) by Toshiba
TLP2958 by Toshiba
PS9513 by Renesas Electronics

Pay attention to safety standards such as UL and VDE.
The reliability and characteristics of these optocouplers are not guaranteed by Fuji Electric.

3.1.2 Primary side current limiting resistor

The current limiting resistor on the primary side should be selected so that sufficient current can flow on the secondary side. Also, deterioration of CTR of the optocoupler over time should be considered in the design of the current limiting resistor.

3.1.3 Wiring between optocoupler and IPM

The wiring distance between the optocoupler and the IPM should be short as much as possible to reduce the wiring impedance. Make sure that the primary and secondary lines of the optocoupler are not close together to reduce the floating capacitance. A high dv/dt is applied between the primary side and the secondary side.

3.2 Optocoupler for alarm signal output and temperature warning output

3.2.1 Optocoupler rating

A general-purpose optocoupler can be used but an optocoupler with the following characteristics is recommended.

- 100% < CTR < 300%
- Single channel type

Example:

TLP781-1-GR rank or TLP785-1-GR rank by Toshiba

Pay attention to safety standards such as UL and VDE.

The reliability and characteristics of these optocouplers are not guaranteed by Fuji Electric.

3.2.2 Input current limiting resistance

The current limiting resistor for the primary side of optocoupler is built in the X-IPMs.
The resistance is R_{ALM}=1.3kΩ. When the optocoupler is directly connected to V_{CC}=15V, IF flows about 10mA. Therefore, external current limiting resistors are unnecessary.
If a large current I_{out} > 10mA is required for the optocoupler output side, it is necessary to increase the optocoupler's CTR value in order to supply the required current.

3.2.3 Wiring between optocoupler and IPM

Note that a high d*v*/d*t* will be applied to the optocoupler for alarm signal output and temperature warning output, please take the same precautions as in section 3.1.3.

4. Connector

For the connector's electrode surface material (plating, etc.), select the same material as the IPM control terminal plating material.

Connectors that conform to the shape of control terminals of X-IPM are commercially available.

For P630: MA49-19S-2.54DSA and MA49-19S-2.54DSA (01) by Hirose Electric

For P631: MDF7-25S-2.54DSA by Hirose Electric

Furthermore, please contact the connector manufacturer for the details of reliability and use of these connectors.

Please note that the reliability and the characteristics of these connectors are not guaranteed by Fuji Electric.

Chapter 5 Cooling Design

This chapter describes the cooling design of the X series IPM.

1. Guidelines for heat sink selection

- To safely operate the IGBT, it is necessary that the junction temperature T_{vj} should not exceed 175°C.
- Additionally, the case temperature T_c should not exceed 125°C.
- Carry out thermal design with sufficient margins so that the junction temperature T_{vj} never exceeds 175°C even during an abnormality such as overload.
- There is a risk of thermal destruction if the IGBT is operated at a temperature above 175°C. Although the T_{jOH} protection function in the IPM activates when the junction temperature exceeds 175°C, however, there is a possibility that the protection cannot work if the temperature rises rapidly. As with the IGBT, junction temperature of FWD should not exceed 175°C too.
- The heat sink temperature should be measured just below the center of the chip. Please refer to the IPM specification sheet for the chip layout drawing. In addition, please refer to the following documents.

  [IGBT Module Application Manual RH984]
  - Power dissipation loss calculation
  - Selecting heat sinks
  - Heat sink mounting precautions
  - Troubleshooting

2. Notice for heat sink selection

Although a guideline for heat sink selection is described in the IGBT Module Application Manual (RH984), please pay attention to the following points.

2.1 Surface conditions of heat sink

Design the heat sink so that the following surface conditions are satisfied. If the roughness and flatness do not satisfy the conditions, it may cause an increase in contact thermal resistance, or insulation failure due to package cracking.

1. The surface roughness of the heat sink should be 10μm or less.
2. The surface flatness of the heat sink should be within +50μm (-50μm) per 100mm, taking the straight line connecting the center points of the two screw mounting holes as reference. Here, "+" (plus) is defined when the heat sink has a convex shape, and "-" (minus) is defined when the heat sink has a concave shape. If both shapes exist, the sum of the absolute values of the maximum and minimum values should be 50μm or less.

Figure 5-1 shows the definition of surface roughness and flatness of the heat sink.

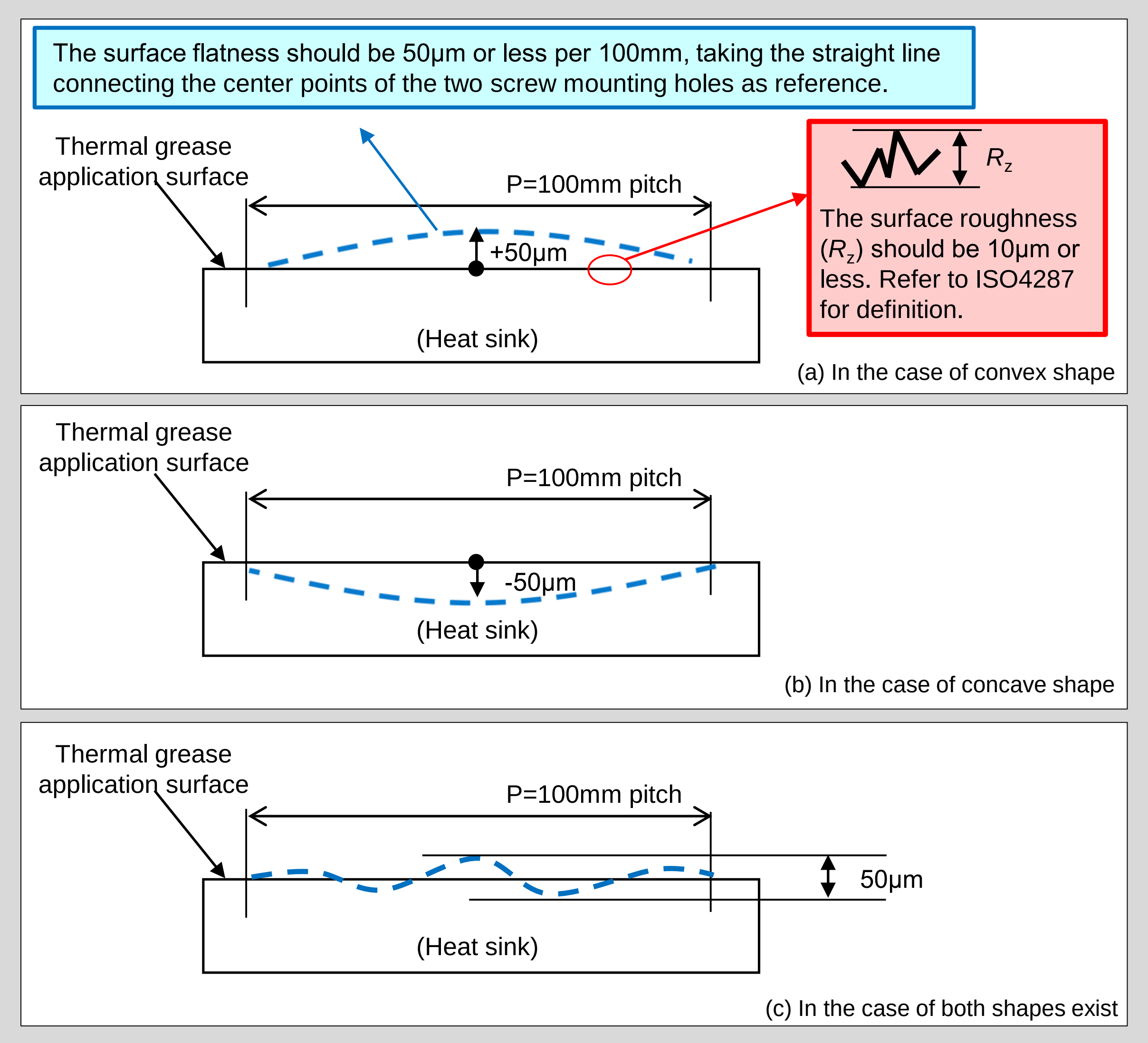


Fig.5-1 Heat sink surface flatness and roughness

3. Mounting instruction of the IPM

3.1 Layout of IPMs on a heat sink

The thermal resistance varies depending on the IPM mounting position. Please note the following :

- When one IPM is mounted to a heat sink, it is recommended to place the IPM on the center of the heat sink to minimize the thermal resistance.
- When multiple IPMs are mounted to a single heat sink, the IPMs location and layout should be designed in consideration of the generated losses and the spread and flow of heat on the heat sink. Allocate the largest area to the IPM which generates the largest loss.

3.2 Application of thermal grease

Thermal grease must be applied between the product mounting surface and the heat sink to ensure heat dissipation from the product to the heat sink. Thermal grease should be applied to the mounting surface of the product.

Improper thermal grease characteristics, application amount, and application method can lead to thermal breakdown due to deterioration of heat dissipation caused by thermal grease not spreading sufficiently throughout the product, or to a reduction in product life due to degradation or depletion of thermal grease during high temperature operation or temperature cycling. Pay attention to the selection and application method of the thermal grease.

Assuming that the thickness is uniform, the required amount (weight) of thermal grease can be calculated from the following formula.

$$\text{Thermal grease weight (g)} \times 10^4 = \text{Thermal grease thickness } (\mu m) \times \text{Base plate area of module } (cm^2) \times \text{Density of thermal grease } (g/cm^3)$$

The stencil method of application is recommended to control proper thickness (Fig.5-2). The recommended stencil mask pattern can be provided upon request.

The spreading of thermal grease can be checked by removing the product after mounting. Make sure that the thermal grease is well spread over the entire product mounting surface.

When applying thermal grease, should check not only the spread of the thermal grease over the entire surface of the product, but also the heat dissipation of the product.

Fuji Electric confirmed that the spreading which is not a problem in actual use using ELECTROLUBE's HTC thermal grease with our specified stencil masks and heat sinks of the shape described in our specifications. Table 5-1 shows typical characteristics of HTC thermal grease.

Additionally, the use of phase change thermal interface material and thermal sheet may cause excessive stress on the product as described below.

- Phase change thermal interface material :

When the grease solidifies, its hardness increases significantly compared to normal thermal grease. If there is a step between the fastening points due to the grease, the product may be subjected to excessive stress at the step when fastening the product. To reduce product stress during fastening, consider measures such as increasing the fastening torque in stages, fastening while heating and softening the grease. After the grease softens and spreads, the tightening torque may decrease. Consider measures such as retightening within the specified torque range or using spring washers.

- Thermal sheet :
  If there is a step between the fastening points due to the sheet, the product may be subjected to excessive stress at the step when fastening the product. Please consider placing the sheet over the entire backside of the product, including around the heat sink fastening screw holes.

The above explanation shows the basic concept of thermal grease, but when using it, customer is responsible for making the decision to apply it with sufficient application verification.

Table 5-1 Typical characteristics of HTC thermal grease and recommended thickness

	Unit	Value
Viscosity (23deg.C, 1RPM)	Pa･s	202 ~ 205 *
Thermal conductivity	W/m･K	0.9 *
Average thickness after spreading	μm	100 +/- 30

* Excerpt from HTC Technical Data Sheet

Table5-2 Base plate area of IPM

Package	Base plate area (cm^2)
P639	14.74
P629	21.71
P626, P644	22.77
P636, P638	41.17
P630	55.67
P631	141.24

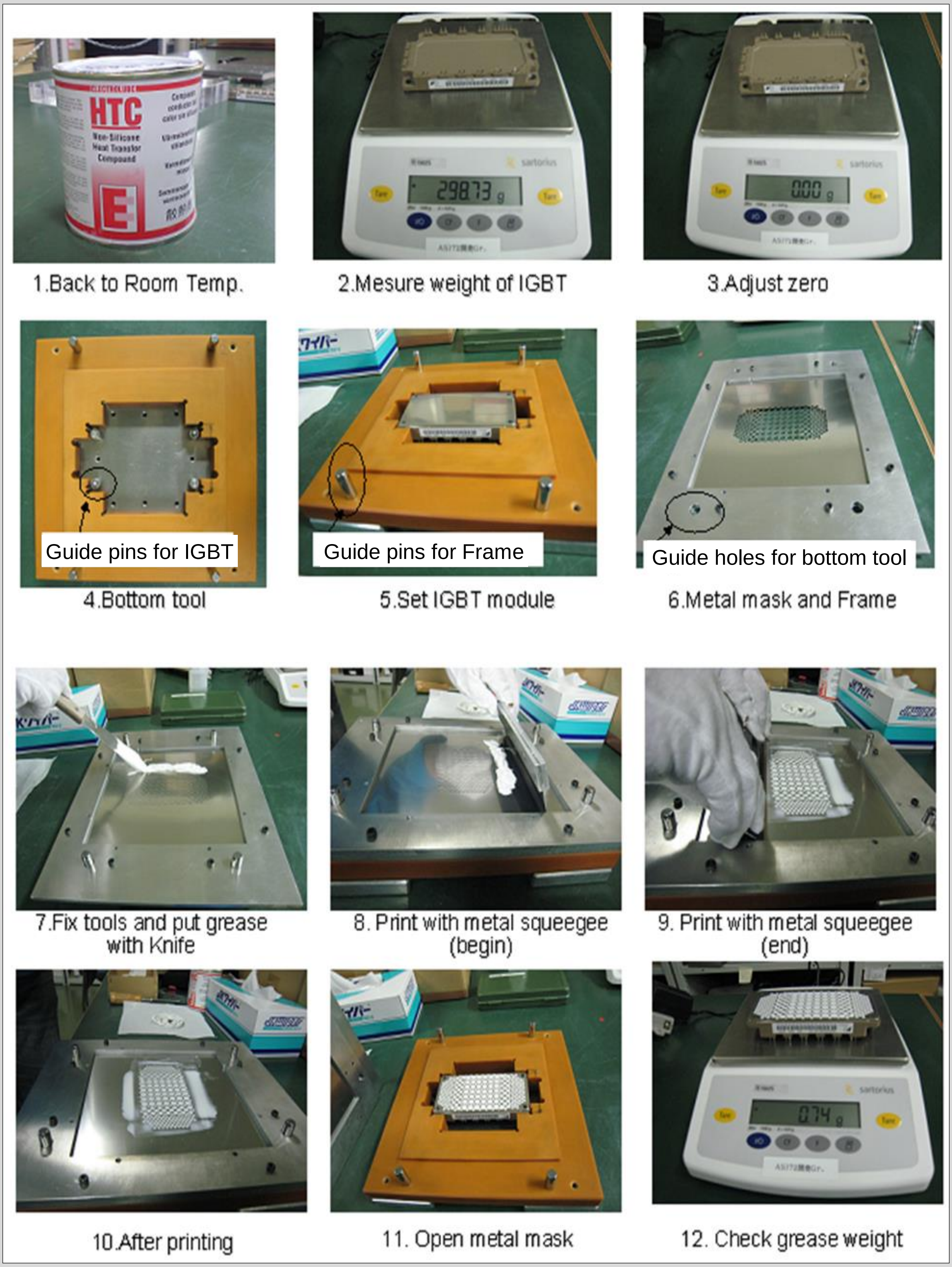


Fig.5-2 Outline of a thermal grease application method

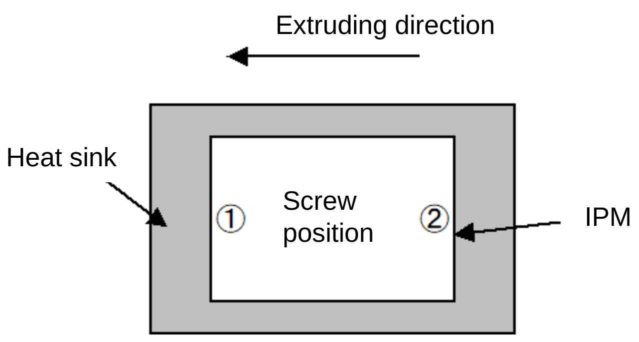
3.3 Screw tightening

Figure 5-3 shows screw-tightening procedures when mounting an IPM to a heat sink. It is recommended to tighten all screws with the specified tightening torque. In addition, spring washers are recommended for the screws.

The specified tightening torque is described in the specification. If the screw tightening torque is insufficient, the contact thermal resistance may increase and screws loosening may occur during operation. On the other hand, if the screw tightening torque is excessive, the case may be damaged.

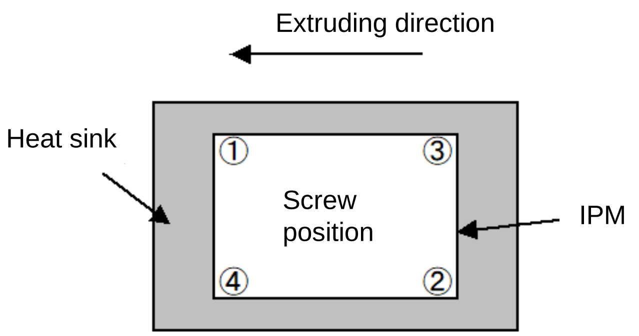
3.4 IPM mounting direction

When an IPM is mounted on an extruded heat sink, it is recommended that the IPM is mounted in parallel to the extrusion direction as shown in Figure 5-3. The purpose is to reduce the effect of heat sink deformation.



	Torque	Order
1st time (initial tightening)	0.5±0.1N･m	①→②
2nd time (permanent tightening)	Specified value	②→①

(a) IPM with 2-points mounting



	Torque	Order
1st time (initial tightening)	0.5±0.1N･m	①→②→③→④
2nd time (permanent tightening)	Specified value	④→③→②→①

(b) IPM with 4-points mounting

Fig.5-3 IPM mounting method

3.5 Verification of chip temperature

After selecting a heat sink and the IPM mounting position is decided, measure the T_c (directly below the chip) and T_f (directly below the chip), and verify the chip junction temperature (T_{vj}).

Figure 5-4 shows an example of how to accurately measure the case temperature (T_c). Please measure the case temperature directly below the chip. The chip location is described in the specification.

Please verify that the case temperature does not exceed 125°C, the chip junction temperature does not exceed 175°C and the thermal design meets the required life time of the system.

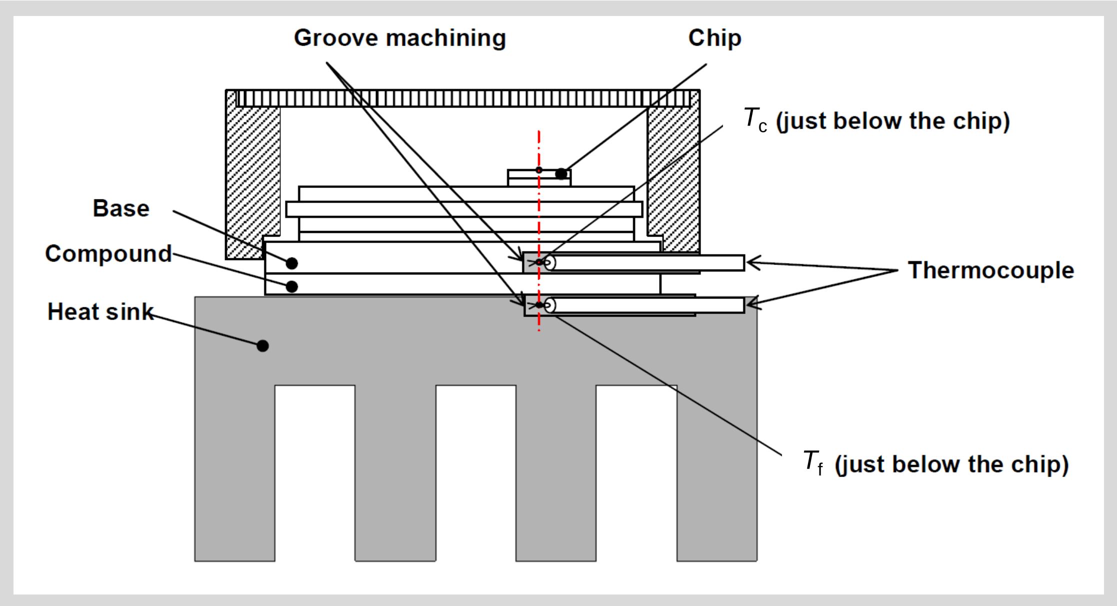


Fig.5-4 Measuring the case temperature

Chapter 6 Precautions for use

This chapter describes the precautions for use.

1. Main power supply

1.1 Voltage range

- The collector - emitter terminal voltage (=V_{CES}) shall never exceed the absolute maximum rated voltage (650V series = 650V, 1200V series = 1200V).
- In order to keep the maximum surge voltage between all terminals within the rated voltage during switching operation, connect the IPM and other components as close as possible to each other and connect a snubber capacitor between P and N terminals. The term ‘between all terminals’ means the terminal arrangement as shown in Table 6-1.

Table 6-1. Terminal arrangement of each package

Package	Between terminals
P639, P629, P626, P630(6in1) P636(6in1), P638	[P-(U,V,W), (U,V,W)-N]
P630(7in1)、P636(7in1)、P644	[P-(U,V,W,B), (U,V,W,B)-N]
P631(6in1)	[P1-(U,V,W), P2-(U,V,W), (U,V,W)-N1, (U,V,W)-N2]
P631(7in1)	[P1-(U,V,W,B), P2-(U,V,W,B), (U,V,W,B)-N1, (U,V,W,B)-N2]

- For P631, connect the main power supply between paired terminals (P1 and N1 or P2 and N2). Do not connect the main power supply between unpaired terminals (P1 and N2 or P2 and N1) as this may cause a malfunction. Connecting snubber circuits to both P1-N1 and P2-N2 is effective in suppressing surge voltage.

1.2 Measures against exogenous noise

- Although measures against exogenous noise are taken in the IPM, there is a possibility where malfunction and breakdown are triggered by exogenous noise depending on the noise kind and intensity. It is necessary to take sufficient measures against noise applied to the IPM.

1.2.1 Measures against noise from outside of the device

- Take measures such as installing a noise filter along the AC line and strengthening earth ground.
- Add a capacitor of <100pF between signal input line and signal GND of every phase if necessary.
- If an excessive noise voltage is applied to the alarm signal output terminal, it may cause incorrect alarm signal output. Connect 0.2kΩ to 1kΩ resistor in series to the alarm signal output terminal if necessary. In this case, choose the most suitable resistance value in consideration of CTR of the optocoupler.
- To prevent noise from entering from the AC line, connect a grounding capacitor of about 4700pF between each of the 3 phases of AC input and ground.
- Apply measures such as provision of an arrester against lightning surge.

1.2.2 Measures against internal noise from the IPM

- Outside of rectifier: Apply the same measures as in Section 1.2.1.
- Inside of rectifier: Add snubber capacitors or similar circuit to the P and N line.

1.2.3 Measures against noise from output terminals

- Apply measures outside of the module to prevent contactor switching surge or others from entering the device.

2. Control power supply

2.1 Voltage range

- The control power supply voltage including ripple shall not exceed the specification value.

Tabe.6-2 IPM operation by control power supply voltage value

Control power supply voltage (V_{CC}) [V]	IPM operation	Control power supply under voltage protection (UV)	IPM input signal voltage	IGBT operation
$0 \leqq V_{CC} \leqq 5.0$	Control IC does not operate correctly and IGBT gate signal is unstable. In addition, IGBT is not turned on because V_{CC} is lower than the gate threshold voltage V_{th}. The UV protection does not work and no alarm signal is output.	–	Hi	–
			Lo	–
$5.0 < V_{CC} \leqq 11.0$	Control IC operate. However, IGBT remains OFF state because UV protection is activated. UV alarm signal is output.	Activated	Hi	OFF
			Lo	OFF
$11.0 < V_{CC} \leqq 12.5$	(1) When UV protection is activated: the IGBT remains OFF state and the alarm signal is output. (2) When UV protection is not activated: The IGBT operation follows the input signal, no alarm signal is output.	(1) Activated	Hi	OFF
			Lo	OFF
		(2) Cancelled or before action	Hi	OFF
			Lo	ON
$12.5 < V_{CC} \leqq 13.5$	UV protection is not activated. The IGBT operation follows the input signal. Power dissipation tends to increase and emission noise tends to decrease.	Cancelled	Hi	OFF
			Lo	ON
$13.5 < V_{CC} \leqq 16.5$	It is recommended voltage range. IGBT driving circuit operates stably. The IGBT operation follows the input signal.	Cancelled	Hi	OFF
			Lo	ON
$16.5 < V_{CC} \leqq 20$	UV protection is not activated. The IGBT operation follows the input signal. Power dissipation tends to decrease and emission noise tends to increase. The short circuit current will increase due to shifts in protection characteristics.	Cancelled	Hi	OFF
			Lo	ON
$V_{CC} < 0$, $20 < V_{CC}$	The use of V_{CC}<0V or >20V may cause malfunction or damage to the device. Never apply such voltage to the device.	–	–	–
			–	–

2.2 Voltage ripple

- The recommended voltage range of V_{CC} is from 13.5 to 16.5V, including voltage ripple.
- The control power supply should be designed with sufficiently low voltage ripple.
  In addition, the noise on the power supply voltage should low as much as possible. If the control power supply voltage exceeds the recommended voltage range, the IPM may cause a malfunction.
- Design the control power supply so that the dv/dt does not exceed 5V/μs.
  Additionally, it is also recommended that fluctuation of the power supply voltage be within ±10%.

2.3 Control power supply startup/shutdown sequence

- Make sure that the control power supply voltage V_{CC} is within the recommended voltage range, before applying the main power supply (between P-N terminals).
- Shut off the main power supply before shutting off the control power supply (V_{CC}).
- If main power supply is applied to the P-N terminals before the V_{CC} reaches the recommended voltage range, or if main power remains, the IPM may cause malfunction or be destroyed due to exogenous noise.

2.4 Alarm signal output during startup/shutdown of control power supply

- UV alarm signal is output during startup of the control power supply.
  The alarm signal is reset after $t_{ALM(UV)}$, but the IPM ignores the input signal unless the protection reset condition is met. The input signal is accepted when all the conditions to reset protection operation functions is met (dissolving of protection factor, elapse of $t_{ALM(UV)}$ and input signal OFF).The driving control circuit should be designed to generate input signals after the alarm signal output period elapsed.
- The alarm signal is output during shutdown of the control power supply.
- Refer to Chapter 3, section 5 for the timing chart.

2.5 Notes on the design of control circuit

- Use four isolated power supply units for the control power supply V_{CC} (3 for upper arm and 1 for lower arm) .
  In addition, it is recommended to connect a capacitor with good frequency response characteristic close to each control power supply terminal in order to suppress transient voltage fluctuation.
- The control circuit should be designed with sufficient current supply capacity in consideration of the consumption current specification (I_{cc}).
- In order to prevent malfunction, pay attention to the distance from other phase wiring and how to parallel, and use a pattern layout that is not easily affected by crosstalk.
- Connect a capacitor between V_{CC} and GND in high-speed optocouplers.
- Use a high-speed optocoupler with tpHL, tpLH ≤ 0.8μs and of high CMR type for the control signal input circuit.
- Use a low-speed optocoupler with CTR ≥ 100% for the alarm signal output circuit.
- Note that if a capacitor is connected between the input terminal and GND, the response time of the optocoupler becomes longer.
- Minimize the wiring length between the optocoupler and the IPM, and the pattern layout should be designed to minimize the floating capacitance between the primary side and the secondary side of the optocoupler.
- The primary side current of the optocoupler I_F should be designed with sufficient margin in consideration of CTR. In order to suppress the influence of noise, design the pull-up resistor on the secondary side of the optocoupler as low as possible to lower the impedance.

3. Protection functions

As described in Chapter 4 “Typical Application Circuits“, it is necessary to determine the I_F of the primary side of the optocoupler so that the total current of the current flowing through the pull-up resistor I_R and the constant current I_{in} can flow on the secondary side of the optocoupler.
If the I_F is insufficient, the secondary side may malfunction. However, since optocouplers have a limited lifetime, it is necessary to consider the lifetime when selecting the primary side current limiting resistor. In addition, the availability of the upper phase alarm signal output differs depending on the package. Check the alarm specification of the IPM in Chapter 3.1, "List of functions".

3.1 General protection operation

3.1.1 Range of protection

- The protection function of IPM is designed to handle non-repetitive abnormal operations. Ensure that abnormal operation is not repeated. In the worst case, the IPM may be destroyed. Over current and short-circuit protection are guaranteed under the condition that the control power supply voltage is from 13.5 to 16.5 V and the main power supply voltage is from 200 to 400 V (650 V series) or 400 to 800 V (1200 V series).

3.1.2 Action on occurrence of alarm signal output

- If an alarm signal is output, stop the input signal to the IPM and shutdown the system immediately.
- The protection functions protect the IPM against abnormal operation, but they are not able to eliminate the causes.
- If an abnormal operation is detected in the upper arm, only the IGBT of the detected phase is turned off and an alarm signal is output from the same phase (excluding P629 and P639). At this time, Switching operation of other phases are permitted.
- On the other hand, when an abnormal operation is detected in the lower arm of the inverter part, all the IGBTs in the lower arm of the inverter part are turned off regardless of the phase and an alarm signal is output from the lower phase. At this time, Switching operation of the upper arm and brake part are permitted.
  When an abnormal operation is detected in the brake part, all the IGBTs of the lower arm(including brake part) are turned off and an alarm signal is output from the lower arm. At this time, Switching operation of the upper arm are permitted.

3.2 Precautions for protection operation

3.2.1 Over current (OC)

- If the over current continues for more than t_{dOC}, the IGBT is judged to be in OC state and is slowly turned off. At the same time, an alarm signal is output.
- If the current drops below the over current protection level within the t_{dOC} period, the OC protection is not activated and the IGBT is turned off normally.
- There is no alarm signal output function in the upper arm of P629 and P639, but the OC protection works and the IGBT is turned off slowly.

3.2.2 Short-circuit (SC)

- If the short-circuit current continues for more than t_{dSC}, the IGBT is judged to be in SC state and the is turned off slowly. At the same time, an alarm signal is output.
  If the short-circuit current drops below the protection level within the t_{dSC} period, the SC protection is not activated and the IGBT is turned-off normally.
- There is no alarm signal output in the upper arm of P629 and P639, but SC protection works and the IGBT is turned off slowly.

3.2.3 Ground fault

(1)Ground fault protection and alarm signal output of upper arm IGBT

- When the ground fault current flows through the IGBT of the upper phase more than t_{dOC} or t_{dSC}, the OC (SC) protection is activated, but the alarm signal differs depending on the package.
  P629, P639 : The upper arm are protected by the OC (SC) function, but does not output the alarm signal.
  P626, P630, P631, P636, P638, P644 : The upper arm are protected by the OC (SC) function and the alarm signal is output.

(2)Ground fault protection and alarm signal output of lower arm IGBT

- When the ground fault current flows through the IGBT of the lower arm more than t_{dOC} or t_{dSC}, the OC (SC) protection is activated and the alarm signal is output for all packages.

3.2.4 Start up under short circuit or ground fault status

- The protection is not activated in case of the input signal pulse width that is less than the dead time because the OC/SC protection has a dead time(t_{dOC}, t_{dSC}). Especially, if the IPM starts up under a load short-circuit condition, and the input signal pulse width is shorter than the dead time for a long time (tens of mill seconds), the chip temperature rises rapidly because the protection function does not work. In this case, even if the IGBT chip over heating protection (T_{jOH}) operates against a rise in chip temperature, the protection does not work in time because the T_{jOH} dead time is about 1 ms, and the chip may be damaged by over heating. In addition, when the power is turned on, the FWD chip may be destroyed because the charging current of an electrolytic capacitor flows in the path of AC power → ground → output terminal → FWD chip → electrolytic capacitor.

3.3 IGBT chips over heating protection

- IGBT chip over heating protection (T_{jOH}) is built into all IGBTs including the brake IGBT. T_{jOH} works when the IGBT chip is over heated abnormally. Not building in a case over heating protection, the X-IPM is not protected against the case over heating. Please implement the protection for case over heating if necessary.

3.4 Protection of FWD

- FWDs have no protection functions.

4. Power cycling capability

- The lifetime of semiconductor products is not permanent. Note that thermal fatigue caused by temperature rise/drop restricts the lifetime. If temperature rise and drop occur continuously, the reduction of the temperature change is required.
- The thermal fatigue life due to temperature changes is called the power cycling capability (withstand capacity), and there are the following two patterns.
  ① Δ T_{vj} power cycling capability : Lifetime caused by chip temperature change that occurs in a relatively short cycle (Mainly due to deterioration of the wire junction on the chip surface)
  Please refer to MT6M15364 for the Δ T_{vj} power cycling capability curves.
  ② Δ T_c power cycling capability : Lifetime caused by copper base plate temperature (T_c) change that occurs in a relatively long cycle (Mainly due to deterioration of solder joint part between the insulated substrate DCB and copper base)
  Please refer to MT5F39952 for the Δ T_c power cycling capability curves.
- Please refer to Chapter 11 "Reliability of power modules" in Fuji IGBT Module Application Manual (REH984).

5. Others

5.1 Precautions for use

① When using the IPM and installing it on the equipment, please refer to the IPM specifications as well.

② Please install a fuse or circuit breaker with sufficient capacity between the input AC power line and the system to prevent secondary destruction in consideration of a destruction of IGBTs/FWDs .

③ Ensure that the switching trajectory at turn-off shall not exceed the RBSOA specification. In addition, the IPM does not define SCSOA because it has a built-in short circuit protection function that detects short circuit current and turns itself off before failure. Ensure that the surge voltage shall not exceed the absolute maximum rating.

④ Before using the product, grasp the environment in which the product will be used and ensure that the reliability of the IPM meets your requirements. If the product is used beyond the specifications, it may cause a malfunction before its design life.

⑤ Even if the product is used within the maximum rating, the product life may vary depending on the temperature and usage environment. Please use it after fully considering the product life and usage environment.

⑥ If the IPM is restarted with a broken power chip, the protection function will not operate properly, which may result in a large-scale destruction. Do not restart the broken IPM.

5.2 Precautions for mounting procedure

① Reduce the contact thermal resistance as much as possible between the IPM and the heat sink by applying thermal grease. (See Chapter 5, Section 3.)

② Use appropriate length of screws. The package may be damaged if the screw length is longer than the screw hole depth. (See Chapter 1, Section 5.)

③ Tightening torque and heat sink flatness should be within the range of specified values.
Wrong handling may cause an insulation breakdown. (See Chapter 5, Section 2.)

④ Do not apply excessive weight to the IPM.
Do not apply deforming forces to the lid. If pushing force is applied to the lid, the internal circuit may be damaged. If pulling force is applied to the lid, it may come off. Do not bend the control terminals.

⑤ Do not apply reflow soldering to the main terminals or control terminals. In addition, be careful so that heat, flux and cleaners for other products do not affect the IPM.

⑥ Avoid places where corrosive gases are generated or where there is an excessive dust.

⑦ Avoid applying static electricity to main terminals and control terminals of the IPM.

⑧ Please confirm that the V_{CC} is 0V before mounting/dismounting the control circuits to/from the IPM.

⑨ Do not make the following connections outside of the IPM:
Control terminal GNDU and main terminal U
Control terminal GNDV and main terminal V
Control terminal GNDW and main terminal W
Control terminal GND and main terminal N (N1, N2 in case of P631)
It may cause malfunction.

⑩ If the IPM is used in a single phase, or if the brake is not used in a built-in brake type, supply the control power to the unused phases as well. Supply the control power and pull up both input terminal (V_{in}) and alarm output terminal (ALM) to V_{CC}. If the control power supply is turned on while the input terminal (V_{in}) is open, the alarm output state will occur.

⑪ If the warning function is not used, it is recommended that the warning pin be left open. If the warning pin is pulled up to V_{CC}, the current consumption by V_{CC}/R_{WNG} increases during warning operation; thus design the control power supply properly. Pulling down the warning pin to GND is not recommended, as a current of about 200uA always flows from the control IC.

⑫ The alarm output is output with different pulse width depending on the protection factor. (See Chapter 3, Section 2.)
The alarm output time on the secondary side of the optocoupler for alarms must be designed in consideration of the delay time of the optocoupler and peripheral circuits..

⑬ The IPM cannot be used in parallel because each IPM has its own driving and protection circuits. If they are operated in parallel, the current may concentrate in a specific IPM and destroy it because of the difference in switching time or the timing of protection..

⑭ The case material meets the standard UL 94V-0, but is not non-flammable.

⑮ The surface temperature of the lid should not exceed the heatproof temperature during soldering. If the solder touches the lid, it may be deformed or the solder may adhere.

⑯ Our IPM is designed for inverter applications. Application to converters requires thorough verification. Please contact us if it is used for converter.

⑰ The brake section is designed on the assumption that resistance load is applied. Please contact us if it is used for inductor load or boost circuit, etc.

Chapter 7 Troubleshooting

This chapter describes the troubleshooting.

1. Troubleshooting

An IPM has various integrated protection functions (such as over current protection and over heating protection) unlike a standard IGBT module, it shuts down safely in the case of abnormal conditions. However, it may be destroyed depending on the abnormality of the failure that occurred. When the IPM has failed, it is necessary to take countermeasures upon clarification of the situation and find the root cause of the breakdown.

Failure tree analysis charts are shown in Figure 7-1. Carry out the investigation of the failure mode by using these charts. For the failure criteria, see Chapter 4, Section 2 [IGBT test procedures] of the IGBT Module Application Manual (RH984).

Furthermore, when an alarm signal output is generated from the IPM, investigation of the root cause by referring to the alarm factor analysis chart in Section 3 of this chapter can be done.

2. Failure tree analysis charts

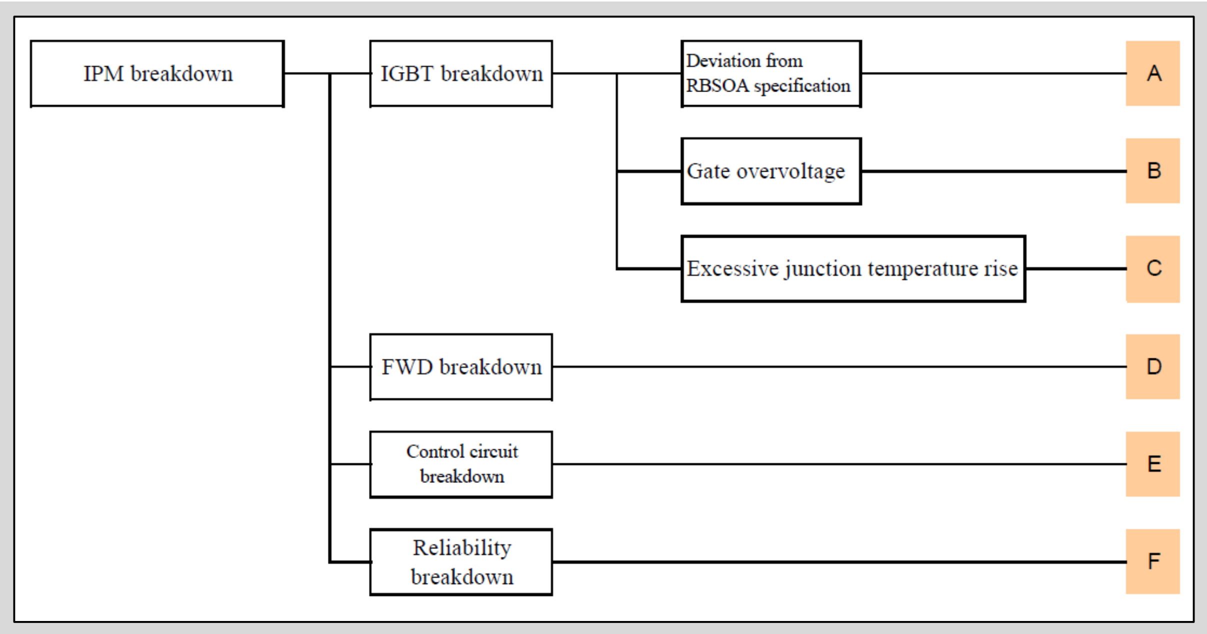
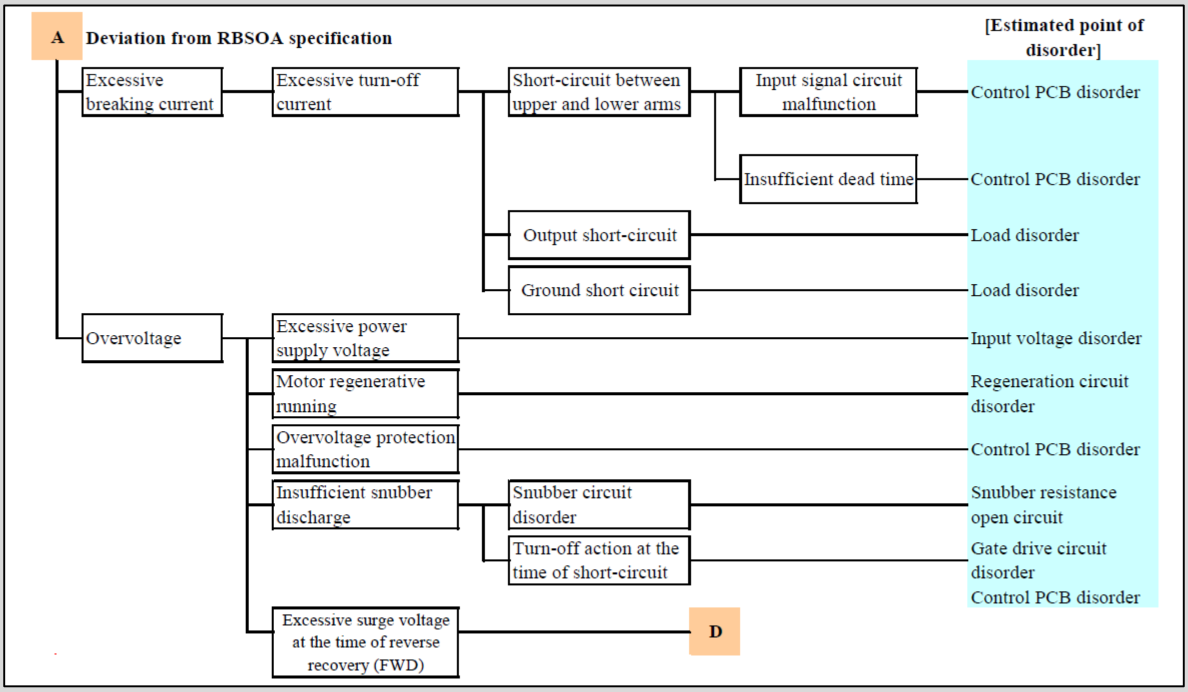
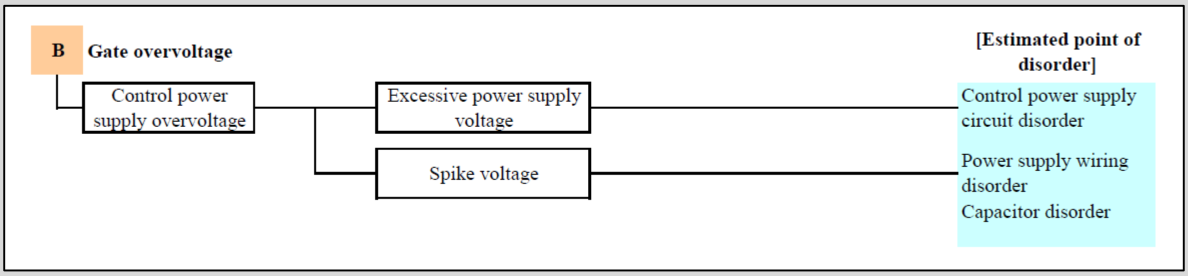


Fig.7-1 IPM failure tree analysis chart
(Symbols A to F are linked with those indicated in separate FTA pages.)

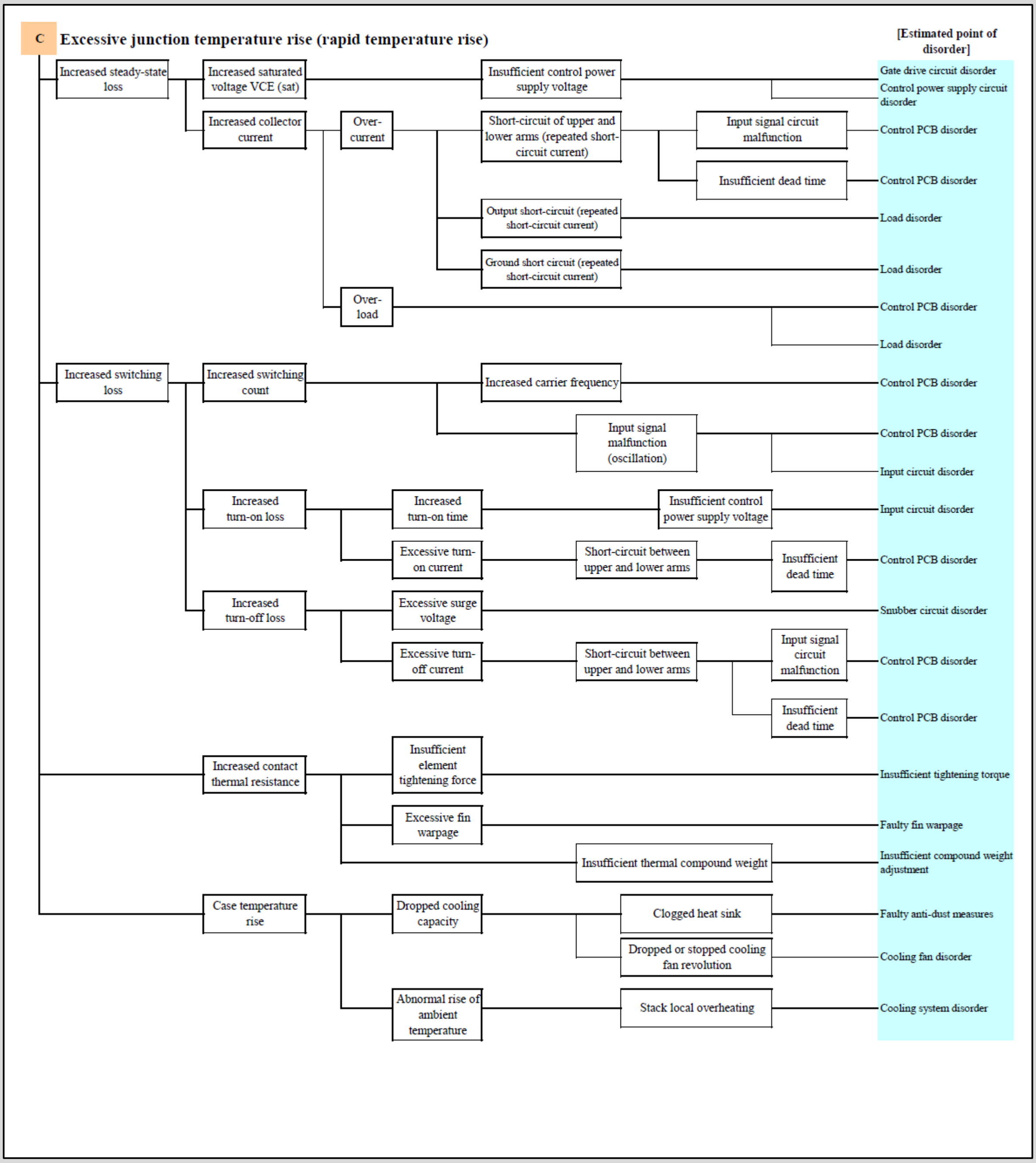


(a) Mode A: Deviation from RBSOA specification



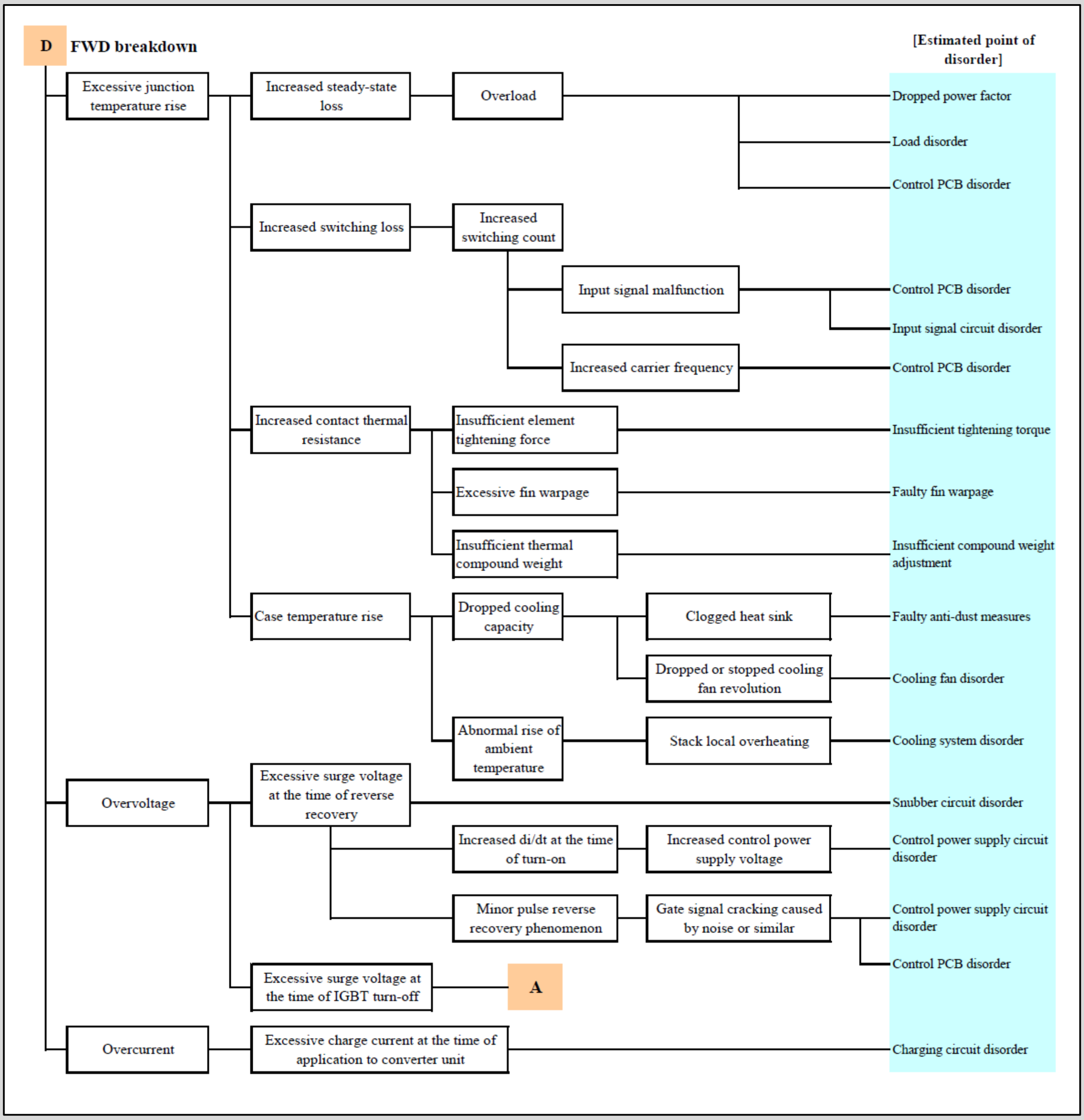
(b) Mode B: Gate overvoltage

Fig.7-1 IPM failure tree analysis chart



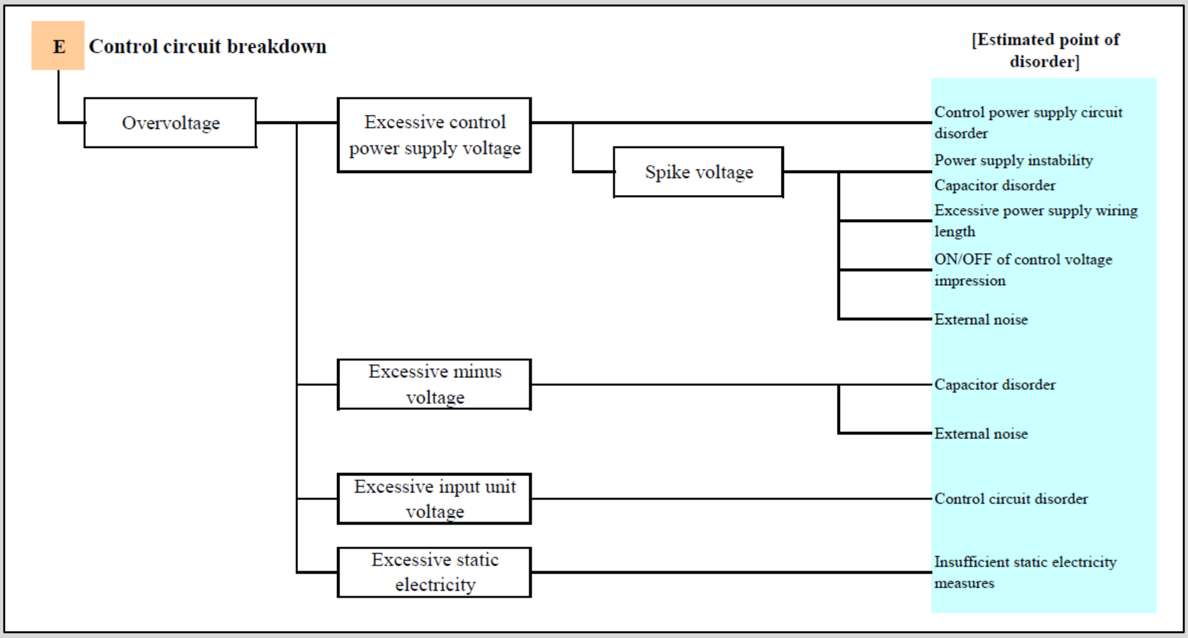
(c) Mode C: Excessive junction temperature rise

Fig.7-1 IPM failure tree analysis chart



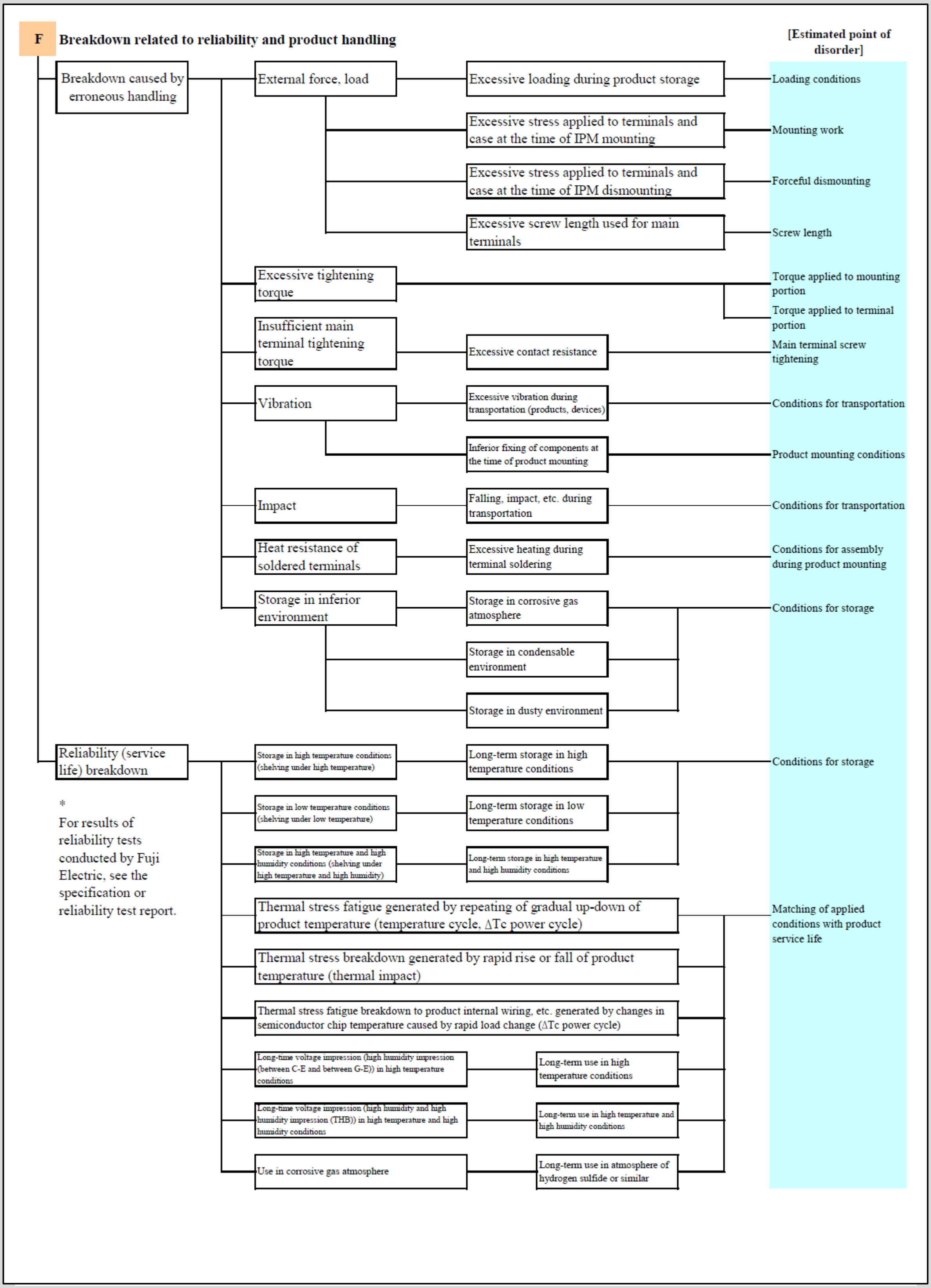
(d) Mode D: FWD breakdown

Fig.7-1 IPM failure tree analysis chart



(e) Mode E: Control circuit breakdown

Fig.7-1 IPM failure tree analysis chart



(f) Mode F: Breakdown related to reliability and product handling

Fig.7-1 IPM failure tree analysis chart

3. Alarm factor tree analysis chart

When the system equipped with the IPM has stopped and an alarm signal is generated, first carry out investigations to identify whether the alarm signal was generated from the IPM or the device control circuit (other than the IPM).

If the alarm signal was generated from the IPM, identify the factor in accordance with the alarm factor analysis tree chart indicated in Figure 7-2.

Similar to V-IPM, it is possible to identify which protection function is activated by checking the alarm signal pulse width in X-IPM too. Therefore, the factor analysis time can be shorten.

In addition, the alarm signal output voltage can be easily measured by connecting a 1.3 KΩ resistor in series between the IPM alarm signal output terminal and the cathode terminal of the optocoupler.

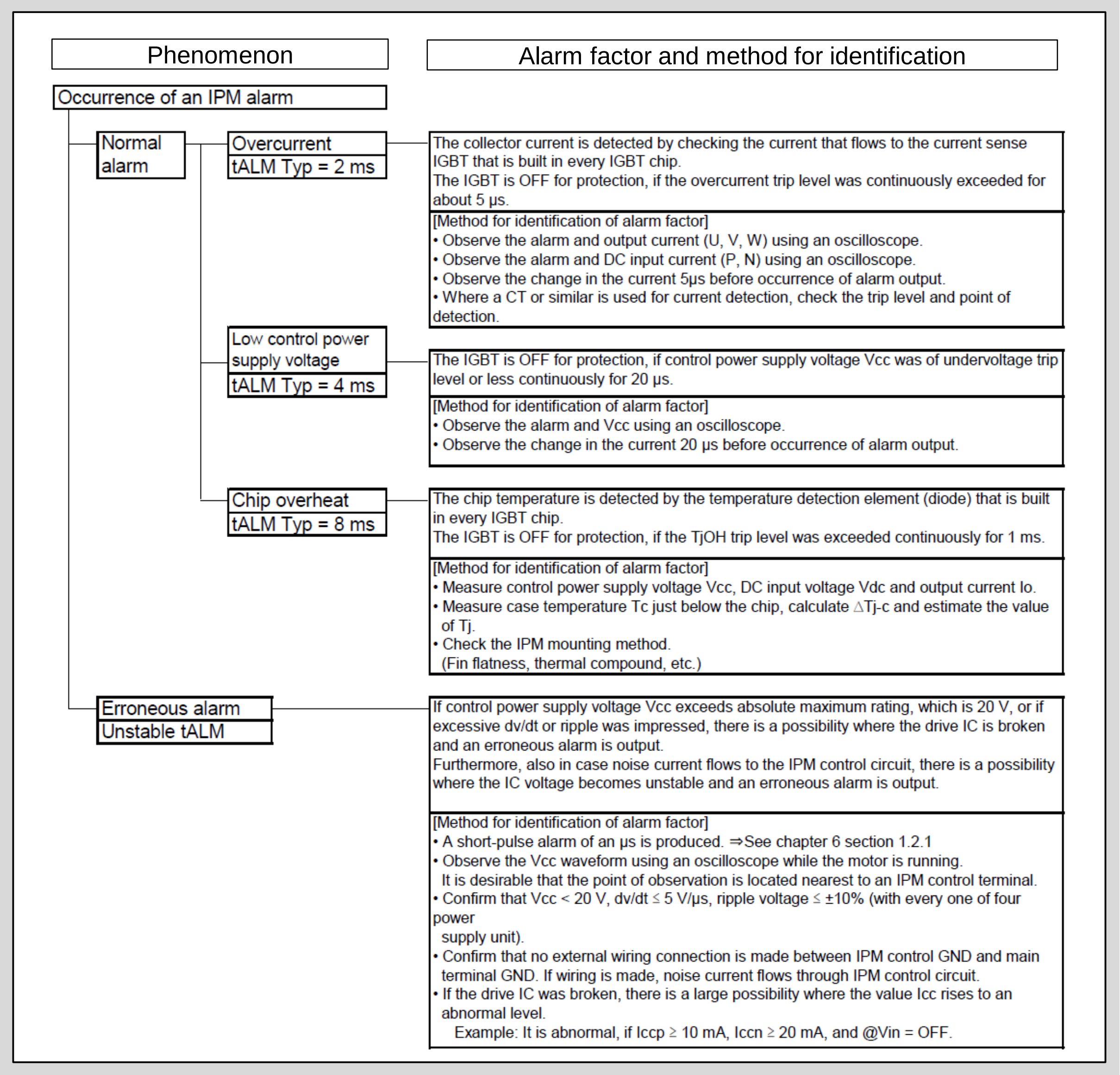


Fig.7-2 Alarm factor tree analysis chart